

Fig. 27 (above)

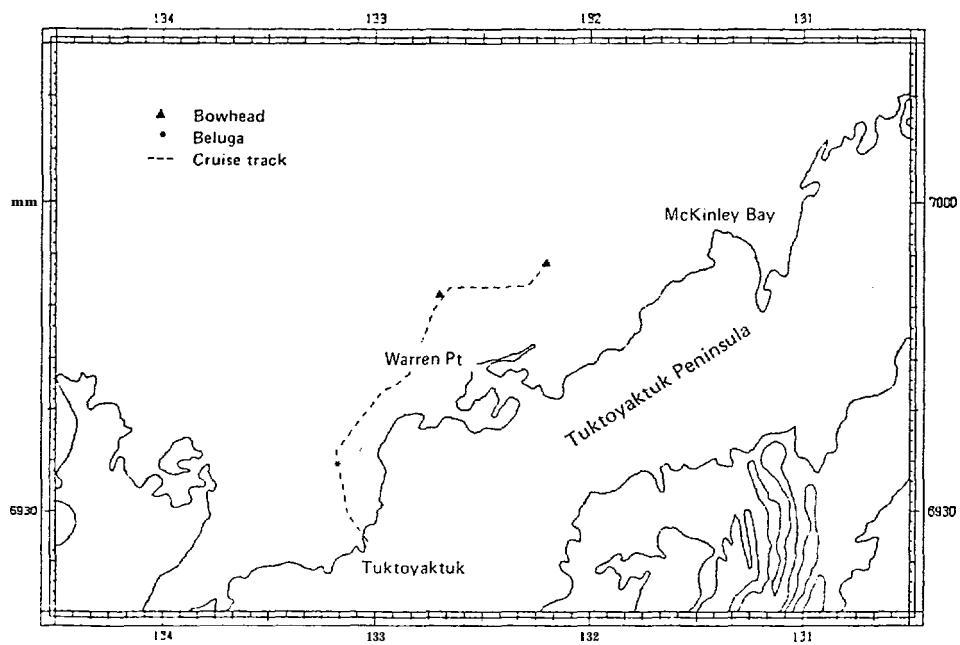


Fig. 28 (above]

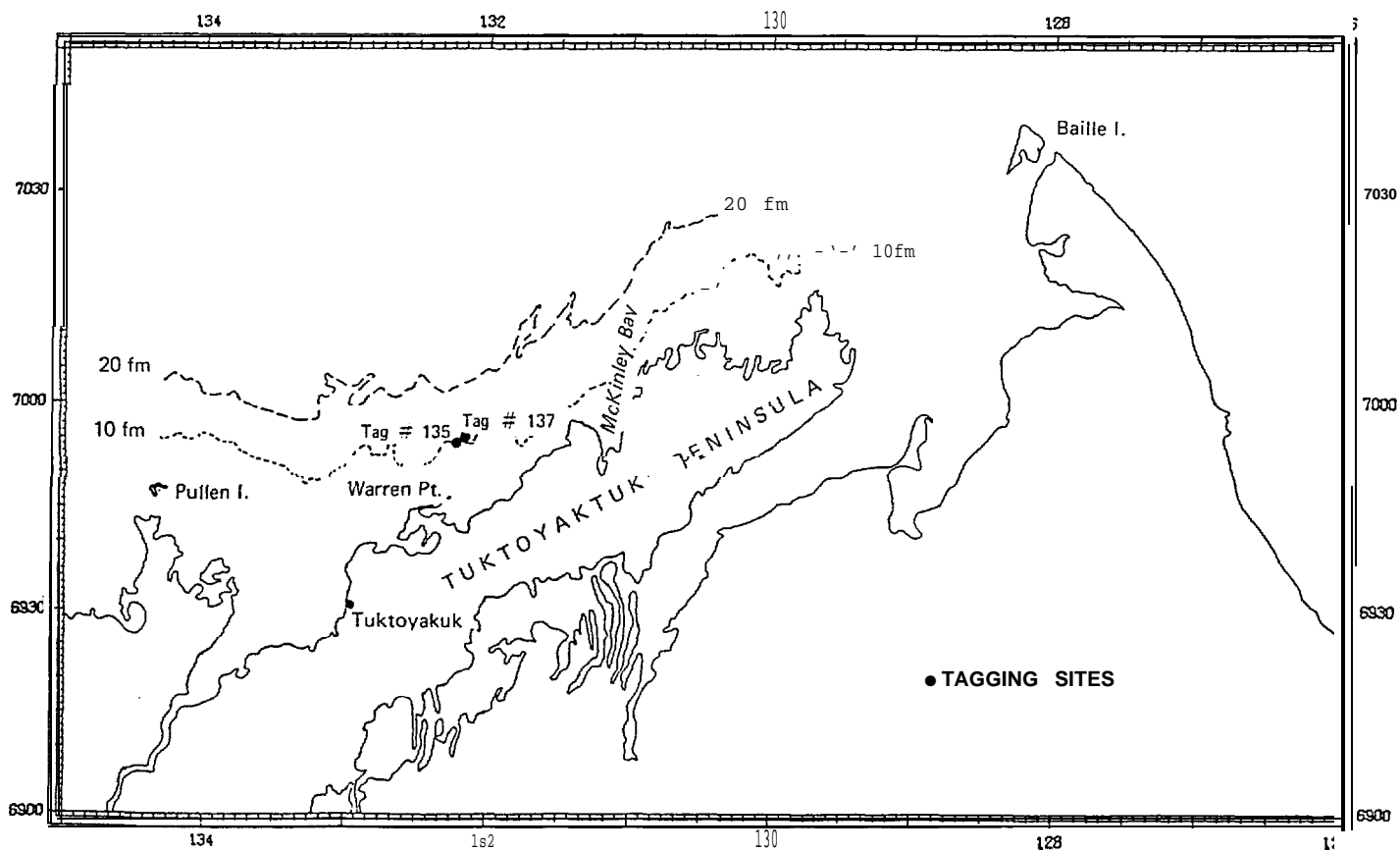
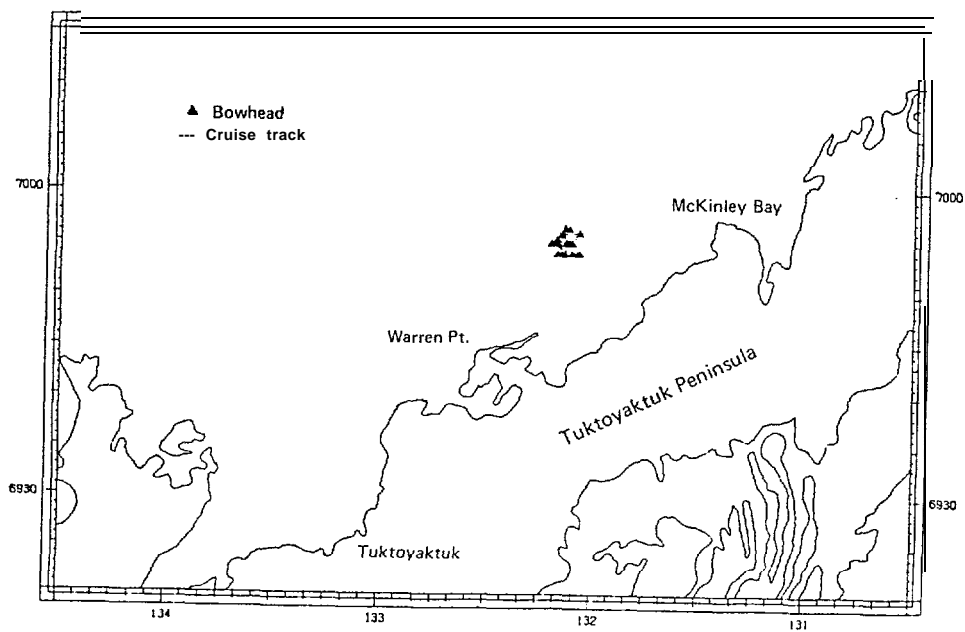


Fig. 29 (above)

Fig. 30 (below)



INSTRUMENTED AND NON-INSTRUMENTED
WHALE SURFACINGS

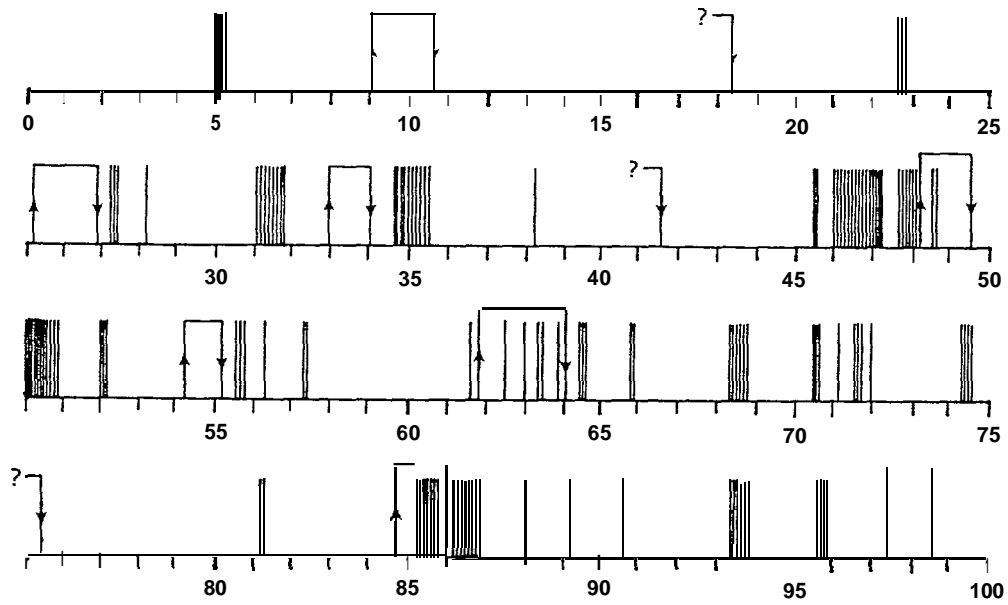
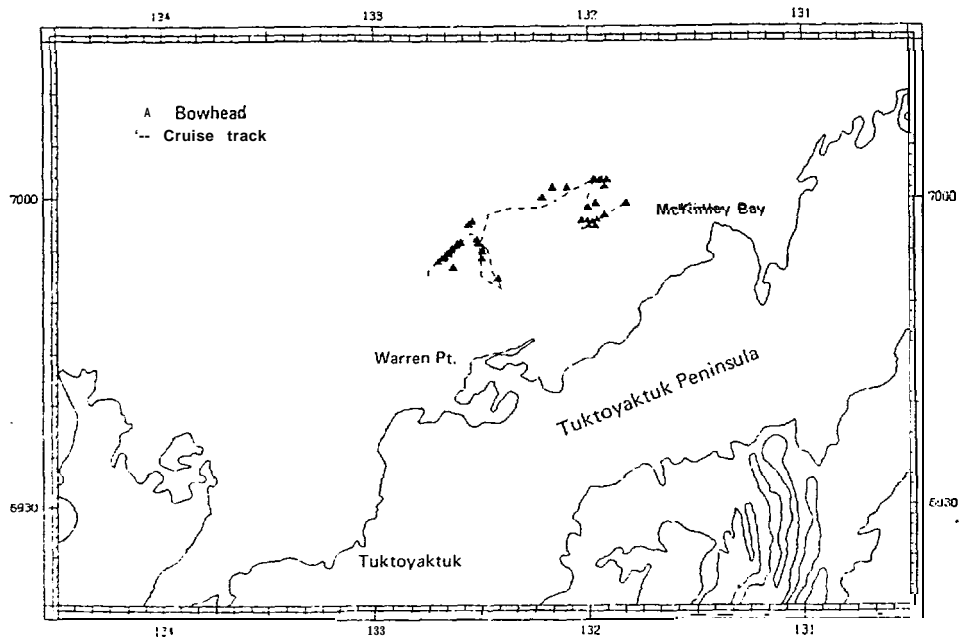


Fig. 31 (above)

Fig. 32 (below)



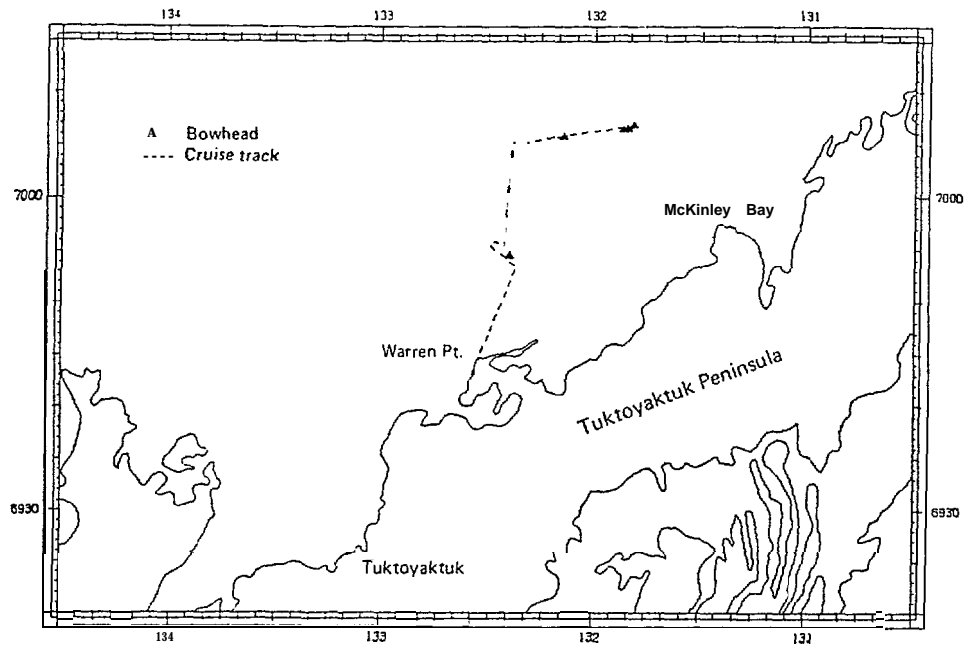
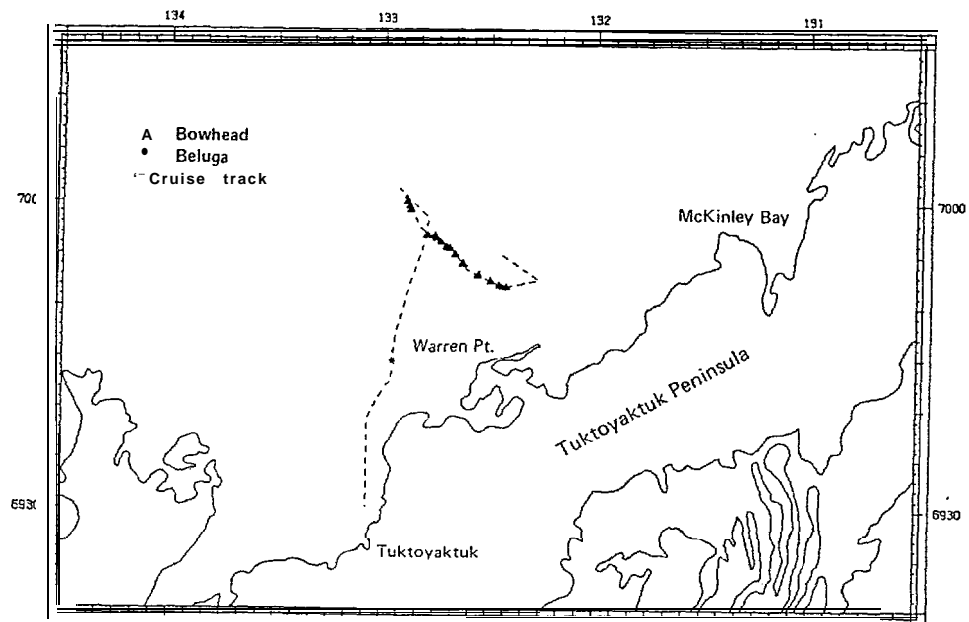


Fig. 33 (above)

Fig. 34 (below)



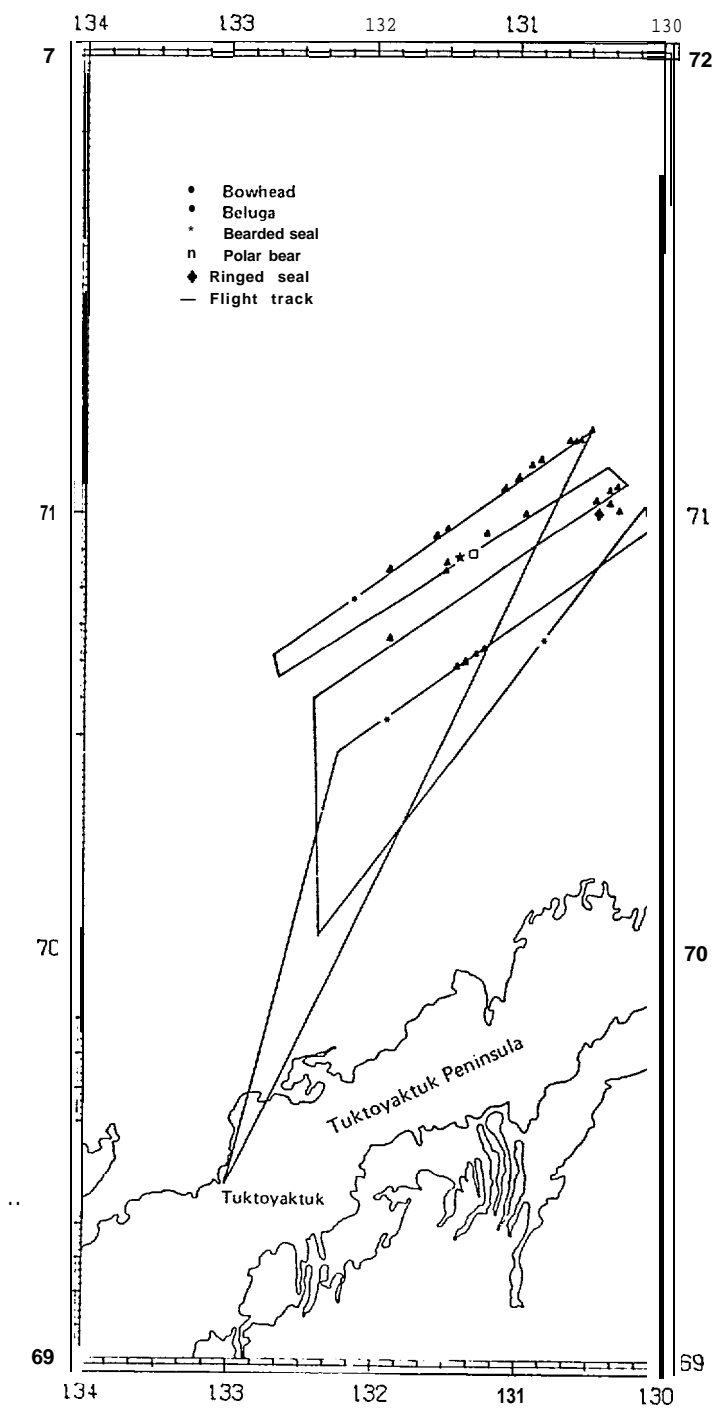
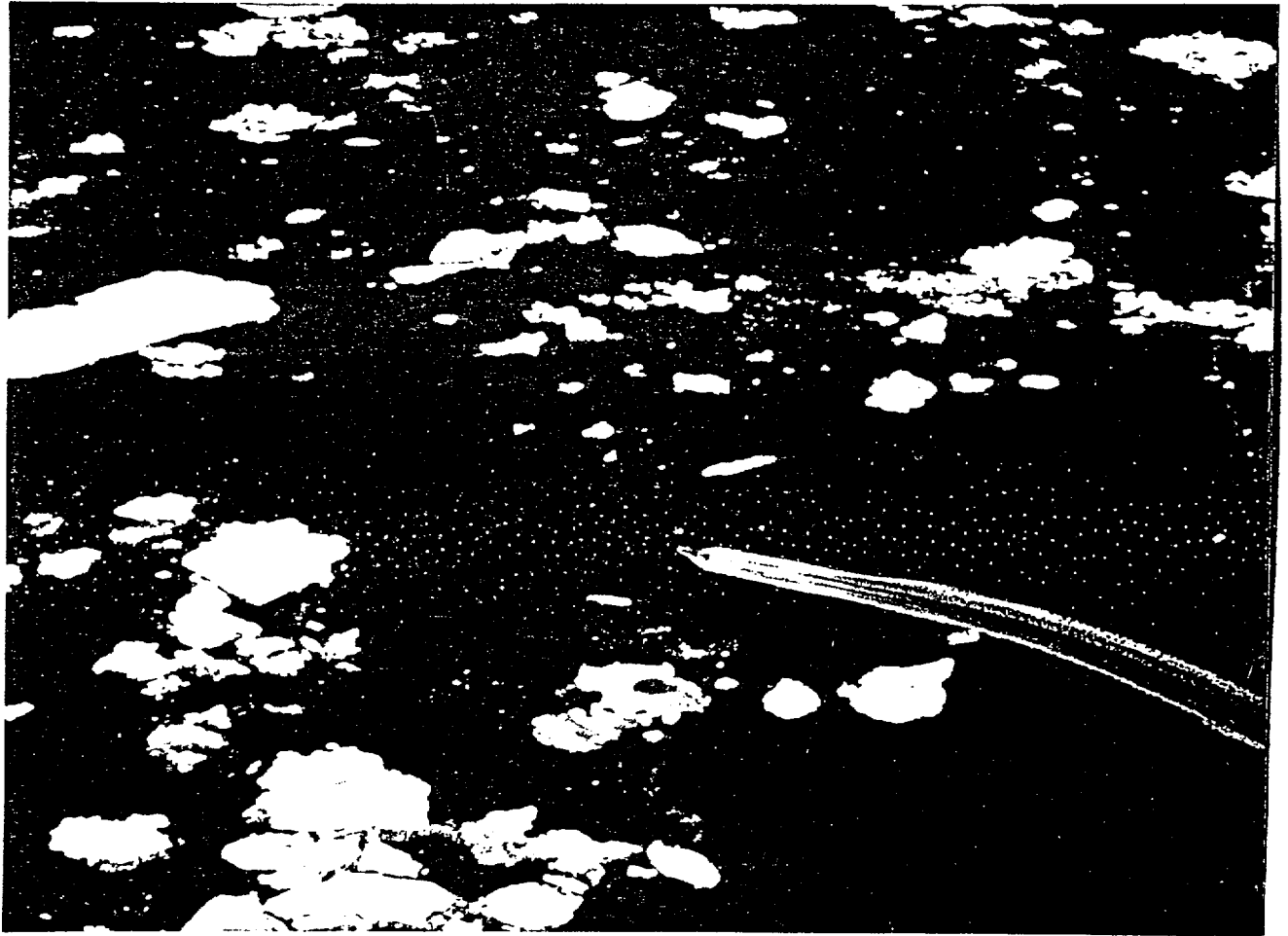


Fig. 35



BOWHEAD WHALE RADIO TAGGING FEASIBILITY STUDY
AND REVIEW OF LARGE CETACEAN TAGGING

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ABSTRACT

This report reviews marking and tagging techniques, their feasibility, success, and history of employment on large cetaceans. Static tags, freeze branding, paint marking, natural marks, and sonic tags are discussed. Emphasis is placed on radio tags. Three radio tracking systems and four types of radio transmitter attachments currently available for large cetaceans are evaluated and discussed.

Results of a feasibility study using a VHF radio tracking system on bowhead whales are presented. On 20 and 21 August 1981 radio tags were deployed on two bowhead whales (Balaena mysticetus) in the eastern Beaufort Sea (69°54'N x 132°12'W). From one whale, signals were received intermittently for 10 min, the other, for one and one-half hours. Reliable dive-surface profiles of tagged whales from these transmissions were not possible. However, dive-surface profiles are reported for a bowhead whale identifiable by natural marks. Efforts to relocate tagged whales from ship and three aerial receiving stations were unsuccessful.

Aerial surveys were flown from 20 July through 12 September, initially to locate whales but ultimately to relocate and track tagged animals. Efforts to relocate tagged whales continued from 16 September through 13 October in collaboration with a BLM (Bureau of Land Management) bowhead survey team working in OCS (Outer Continental Shelf) lease-sale areas. A brief radio transmission was received during one of these surveys but the presence of a tagged whale was unconfirmed by either further transmission or visual relocation. A record of all species of marine mammals sighted on surveys is presented.

The development of a satellite-linked transmitter and requirements for a successful satellite tracking program are discussed.

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INTRODUCTION

There are essentially three types of research possible utilizing radio tracking technology: 1) short term behavior, activity, and habitat utilization studies; 2) **longer** term **migration** and distribution studies, and 3) telemetry studies yielding information about the physiological state of the whales and about their environment. Standard radio frequency (RF) tracking techniques can be used to gather data on behavior (including effects of human disturbance), activity patterns, and telemetry on a short term and rather local basis. However, to gather **longer** term information on habitat utilization, distribution, **migration**, and long term physiological and environmental parameters, **satellite-linked** technology is essential, since logistical and cost factors preclude any other method of **signal** acquisition.

The purpose of this research was to provide an overview of radio tracking potential for **large** cetacean research, to test the feasibility of radio tracking bowhead whales, and to initiate the development of a satellite-linked transmitter (**SLT**) for the remote acquisition of whale location, movement, and distribution data. The specific objectives of the program were to:

- 1) synthesize existing information on **tagging** and tracking systems, addressing the advantages and disadvantages of individual **tags** and tracking systems for **large** cetaceans, and identify the technology **gaps** necessary to advance the state of the art to a safe and reliable level;

- 2) conduct a field experiment to determine the feasibility of radio **tagging** and tracking **bowhead** whales in the Beaufort Sea, ultimately via satellite; and
- 3) design, fabricate and test an SLT for attachment to large cetaceans.

REVIEW OF LARGE CETACEAN TAGGING AND MARKING TECHNIQUES

History

Although man since the earliest times, has studied the lives of the other animals with which he shares his world not until the nineteenth century were systematic marking programs carried out to aid those investigations. Prior to that time careful field studies had provided a large accumulation of information concerning some phases of wildlife natural history, but scientists recognized the need for more information about territory and home **range**, social structure, population structure, and migration routes. Thus tags and marks that had been used primarily to establish ownership or to carry messages were modified, improved, and used **in** conjunction with newly evolving analytical techniques for the rigorous study of the ecology and behavior **of** animals.

The earliest marking studies were carried out on birds and fish. Fisher and Peterson (1964) ascribe the first bird marking to **Quintus Fabius** Pictor. "Sometime between 218 and 201 B.C., when the second Punic War was on, this Roman officer was sent a swallow taken from her nestlings, by a besieged garrison. He tied a thread to its leg with knots to indicate the date of his relief attack, and let the bird fly back." By the eighteenth century a wide variety of birds including falcons, herons, swans, and ducks were marked with various types of name plates and metal collars, and during the late nineteenth century a Dane **by** the name of **Mortensen** developed the aluminum **leg** band which was the foundation for all subsequent bird banding. By the nineteenth century

various fish species were **also** being marked. **Early salmonid** studies using ribbon, brass wire, fin **cutting** and numbered **tags** demonstrated that these species returned to their native rivers to spawn after spending several years at sea.

The first mammals to be systematically marked were the northern fur seals of the **Pribilof** Islands in the midnineteenth century. The seals were marked by removal of the ears to determine their dispersal, movements, and homing specificity to the rookery of their birth. Later, fur seals and other **pinnipeds** were marked by a variety of methods including branding, **dyeing**, painting, hair removal, and many different tag types (**Scheffer** 1950; Hobbs and Russell 1979). By the 1930's the marking of small mammals had become a routine method of study, but the capture and application of **tags** and marks to most large mammals still proved difficult. It was not until the development of safe **drug** immobilization techniques in the 1960's that other **large** mammal marking became a significant research technique. A thorough review of the history and use of animal marking and **tagging** is found in Stonehouse (1978).

Although a **large** number of marking and **tagging** techniques have been developed and used for the study of animals, most cannot be used successfully on cetaceans because of their physical characteristics, habitat, and **general** invisibility above the water surface. Cetaceans have no hair and their **epidermal tissue** sloughs very rapidly so it is impossible to clip them or mark them with paints or dyes. Their body **shape**, fusiform and highly adapted for aquatic **living**, makes it difficult and potentially **dangerous** to the animal to attach identifying objects on the external body surface. Because cetaceans are widely and relatively **sparsely** distributed, they are difficult and expensive to capture and

are essentially impossible to anesthetize in the field for surgical practices. Those cetaceans that live entirely in the oceanic environment pose special problems concerning longevity and decomposition of materials for tags and marks. The problems of capture and handling obviously become more difficult as the size of the cetacean increases.

Despite these overwhelming obstacles, the marking and tagging of cetaceans has long been recognized as the only way to gain insight into the unknown aspects of their life history. There are three generalized methods of recognizing individual cetaceans: 1) natural markings, 2) static tags, and 3) sonic and radio tags. Each method will be discussed and evaluated especially in light of their applicability to the large cetaceans.

Natural markings

Since early times people have been able to identify individual animals by their unique markings. Early whalers, for example, knew of distinctively marked or anomalously colored whales like the famous all-white bull sperm whale (Physeter macrocephalus) after which the novel Moby Dick was patterned. Researchers today use natural markings and unusual appearances to identify individuals and monitor their behavior and movement. Pictorial catalogues, for example, have been compiled of gray whale (Eschrichtius robustus) markings (Swartz and Jones 1980; Darling 1977), humpback whale (Megaptera novaengliae) fluke patterns (Kraus and Katona 1977, 1979; Lawton et al. 1980), and killer whale (Orcinus orca) dorsal fin shapes and coloration patterns (Balcomb 1978, 1980). One of the major questions regarding this method of identification is the reliability and longevity of recognizable markings or deformities.

Available results indicated that identification is possible in most cases over a period of at least a few years and thus valuable data can be gathered about site tenacity over seasons as well as short term migration and home range, social interactions, activity patterns, and habitat use. The main drawbacks of this system are the requisite high labor intensity for data acquisition and the small area of possible coverage. Thus, the limited availability of large, cheap labor pools and local concentrations of cetaceans with a large portion of identifiable individuals often preclude such studies.

Static Tags and Marks

Whalers before the turn of the 20th century occasionally found old harpoons imbedded in the tissues of freshly killed whales, evidence of a previous and unsuccessful hunt. From reports of these harpoons, cetologists conceived of marking whales with labeled harpoons as a means of gathering information on migrations, size of stocks, and effects of exploitation by the whaling industry. Following a successful experimental tagging cruise in 1932/33, an extensive tagging program was undertaken by the British Discovery Investigations using 23 cm-long metal tubes fitted with a ballistic head. These marks, which became known as Discovery tags, were fired from a 12-gauge shotgun into the flesh of the whale. Later, marks were also made for smaller whales and were shot from a 410-gauge shotgun. Each tag was labeled with a serial number and an address for return. A reward was offered for receipt of the tag along with vital information concerning the animal and its taking. Although the Discovery Committee discontinued its involvement in this marking effort in 1939, Discovery-type marking

continues today by agencies in many whaling countries (for review see Brown 1978).

It was not until the 1960's, when interest in cetacean studies greatly increased, that investigators **began** to experiment with methods of **tagging** and marking which did not depend for their success on the **killing** of the animal. As a consequence, a variety of externally visible tags and marks were developed to **give** the investigator a temporary or permanent record of the identity of individual cetaceans.

Because some porpoises and dolphins often ride the bow pressure wave of boats and ships, they are relatively easily captured or **tagged** from a moving vessel. In recent years, at least three types of spaghetti streamers and five types of dorsal fin tags or marks have been placed on small cetaceans.

The **spaghetti** streamers initially tested on cetaceans by Nishiwaki et al. (1966) and Sergeant and Brodie (1969) are **generally** placed just forward of the dorsal fin, a bit to either side of the midline of the back. These tags can be attached to **free-ranging** animals with a pole applicator (Evans et al. 1972) or crossbow (Kasuya and Oguro 1972) and do not require capture. The tag consists of a stainless steel barb which penetrates through the blubber just into the muscle; a stainless steel or monofilament leader which is attached to the barb and passes out through the skin; and an attached streamer which may be a color-coded extension of the leader or a wide, flat strip of tough plasticized material which trails **along** the animal's body. Spaghetti **tags** are numbered and often labeled with an address for return. Because of their small size, the labels cannot be seen on a free-ranging dolphin, even at close range, and specific information can only be obtained when a tag is examined closely on a captured animal

or extracted from an animal, usually postmortem. **Color coding**, however, can often be recognized from a distance and may provide critical information concerning the date and location of **tag** placement and subsequent movement of the animal. Despite early success with spaghetti **tags** (Perrin et al. 1979), extensive testing showed that tag entry wounds did not heal which resulted in **high tag** loss rates and led the National Marine Fisheries Service (NMFS) to discontinue their use for studies in the eastern tropical Pacific (J.C. Jennings, NMFS Southwest Fisheries Center, La Jolla, CA 92038. **Pers. commun.**).

When investigators need more specific and **longer-term** information about the porpoises and dolphins being studied, they may be required to capture the animal and apply more readily visible **tags** and marks with individual **coding**. The dorsal fin is generally chosen as the site for **tag/mark** placement, since it is the most prominent and easily observed portion of a surfacing cetacean and is **thought** to be more durable than other potential sites (Evans et al., 1972). Small triangular **wedges** clipped out of the **tough** connective tissue on the trailing **edge** of the dorsal fin have facilitated identification of individual cetaceans in some studies. Alternatively, button or disc tags are placed near the center of the dorsal fin and are held **on** both surfaces by a central bolt which passes **through** the fin (Evans et al. 1972), and rectangular **visual** tags are held in place with two bolts (Irvine and Wells 1972). The smaller Jumbo roto **tags**, a type of cattle ear **tag**, pivot on a **single** stud which passes through the trailing **edge** of the dorsal fin (Norris and Pryor 1970). Finally, **flag** tags, which also pivot on their leading edge, have been tested in captivity (Evans et al. 1979), but these larger tags

have not, at this writing, been used in the field. The tags mentioned above have characteristic symbols or alphanumeric designations that allow individual identification at varying **ranges** depending on their size.

Freeze brands, symbols and alphanumeric designations applied to skin tissue with irons which have been cooled in liquid nitrogen or dry ice and alcohol, have proven effective as permanent marks which are highly visible at moderate ranges (Cornell et al. 1979; Irvine and Wells 1972). These marks have been placed on the back of small cetaceans (for aerial observers) or on the dorsal fin (for surface observers) causing no apparent discomfort to the animal. Irvine et al. (1979) report a **longevity of at least four years** on a bottlenose dolphin (**Tursiops truncatus**) and Wells (**pers. commun.**) more recently reports over five years from the same dolphin population.

During the mid 1970's a **great** deal of research went into tag and mark development for population studies of the small cetaceans taken incidentally by the tuna fishery in the eastern tropical Pacific. Flow tank and live animal tests provided extensive information on materials and designs including: disc tags, **rototags**, tail stock bands and streamers, spaghetti streamers, hutton tags, surveyor's tape streamers, dorsal **fin** clips, dorsal body clips, fin clip saddles, tetracycline tooth deposit marking, tattooing, and freeze branding (National Fisheries Engineering Laboratory 1978; Evans et al. 1979). Despite **these** exhaustive studies, no optimum static **tag** has been successfully field tested.

The methods described above have been utilized on a variety of smaller cetaceans. However, due to the obvious difficulties of handling

the larger whales, only remote application of tags and marks is practicable. To date, only spaghetti **tags** (Norris et al. 1976), streamer tags (Mitchell and Kozicki 1975; Rice et al. 1979), paint and freeze branding have been tested in external **marking** of large whales. Because the life expectancy of streamer tags is so short and the probability of resighting so poor, only sporadic effort has gone into adapting these methods to whales and the results of such programs have been equivocal (Brown 1978). Paint marking, tested by the senior author on California gray whale barnacles after unsuccessful tests on the skin of porpoise by Watkins and **Schevill** (1976), failed to leave a distinguishing mark after the first submergence, and the freeze brand applied to the released captive gray whale, **Gigi**, was **resighted** only once after early contact was lost (Evans 1974).

Sonic Tags

Leatherwood and Evans (1979) summarized the developmental work in applying acoustic tracking devices to cetaceans as follows:

"Early attempts employed acoustic tracking devices developed for the study of fishes. Schultz and Pyle (1965) attempted to attach acoustic transmitters mounted on shallow harpoon heads to California gray whales. Payne (1967, Rockefeller University, pers. **commun.**) similarly attempted to track humpback whales **using** acoustic devices. In 1967-1968 one of us (Evans) tested the potential use of sonic transmitters attached by a suction cup to a captive **Tursiops truncatus** (unpublished data). None of these attempts met with any success. The primary problems identified were that 1) **ranges** obtainable were unacceptably short; 2) transducers, both transmitting and receiving, were inadequate; and, importantly for

future approaches, 3) the projectors used frequencies that fell within the hearing ranges (e.g., see Johnson 1966) of **these highly** acoustic animals. There were significant problems in all these cases with successful attachment and operation of the transmitters. But even if these technical problems had been overcome, it is **highly** questionable whether data obtained from these systems could have represented "normal" behavioral patterns for the tagged animals.

Even Kanwisher (1978) who reports the successful telemetering of physiological data from unrestrained porpoise muses that "The possibility also arises that, upon realizing they are listening to their own heartbeat, the animals will be fascinated and vary the rate for their own amusement." Watkins (1978) decided early in his cetacean tracking development program not to use sonic devices on these acoustically sensitive animals. A. Blair Irvine (National Fish and Wildlife Laboratory, Gainesville, FL 32601. **Pers. commun.**) found while using sonic **pinters** to study the movements of manatees that ranges were so short (about 400m) that if a **tagged** animal were ever lost they were highly unlikely to relocate it, even in the confines of the St. Johns River. Irvine also found sonic signals to be sharply confined within a the rmal plume and reduced to 30 m reception within the plume. These factors combined with the highly unpredictable sound paths of the oceans, suggest that it is unlikely that any future development in acoustic tracking will produce a system capable of tracking **free-ranging** cetaceans, except for short distances and time spans.

Radio Tags

Cetaceans spend 85% to 95% of their life underwater, move during the night as well as the day, and often vanish from the watchful eye of an observer, even though they may be clearly marked or tagged. The development of tracking devices for whales and porpoises has thus greatly aided investigators in studying the life history of these animals. For a comprehensive review of tracking systems see Michelson et al. (1978) and for one of radio telemetry see MacKay (1970). In 1961, Shevill and Watkins (1966) began development of a radio transmitter for right whales, Eubalaena glacialis, based on the design of the early discovery tag marks. Although the investigators were unsuccessful in tracking whales with these early transmitters, they did serve to show the feasibility of the attachment of radio transmitters to large cetaceans. During this same time period, other investigators (Evans and Sutherland 1963) were also considering the use of telemetry in the study of marine animals. Between 1967 and 1971, Evans (1971), in conjunction with Ocean Applied Research (OAR), developed a small radio beacon that could be attached to porpoises utilizing existing high frequency (HF), citizen band technology. Because of their short surface times, it was immediately evident that automatic direction finding (ADF) capabilities were essential to the successful tracking of free-ranging cetaceans, and so an ADF was developed by OAR for use in the HF band range (Martin et al. 1971).

There followed two basic methods of attaching radio transmitters to large cetaceans: animals were captured and physically restrained in some manner so that a radio transmitter could be attached, and radios were attached by various remote methods. In the former case, Norris attached OAR radio transmitters to gray whale calves with flexible

elastic harnesses in Baja California and successfully tracked them for up to four days (Norris and Gentry 1974; Norris et al. 1977); Evans (1974) attached a radio transmitter to a yearling gray whale with sutures in southern California and tracked that animal sporadically along the California coast; and Erickson (1978) attached a VHF radio transmitter to the dorsal fin of killer whales by using stainless steel pins and tracked the animals intermittently in **Puget** Sound, Washington for five months. Watkins and **Schevill** continued their remotely **implantable** whale beacon testing and development program in conjunction with OAR through the 1970's (for a review of this development program, see **Schevill** and Watkins 1966; Watkins and **Schevill** 1977; and Watkins et al. 1980). Throughout the developmental stage of this radio tag, various design changes have been made, but the concept of a stainless steel shaft implanted within the **body** of **the** whale with only the antenna exposed has remained constant. These radio transmitters have been implanted in a number of species of whales and have evolved with each testing. Ray et al. (1978) tagged and successfully tracked fin whales in the St. Lawrence River; **Tillman** and Johnson (1977) tagged and tracked humpback whales in southeast Alaska in 1976 and again in 1977 (Marine Mammal Division 1977); Watkins et al. (1978; 1981) radio-tagged and tracked finback and humpback whales in Prince William Sound, Alaska; **Watkins** et al. (1979) tagged and tracked **Bryde's** whales (*Balaenoptera edeni*) in Venezuela and Watkins (1981) successfully tagged and tracked fin whales (*B. physalus*) near Iceland.

In 1978, the longevity of systems for the remote attachment of radio transmitters to free-ranging large cetaceans was limited to 17

days (Watkins et al. 1978). Beginning in that year, alternate systems were developed to increase the lifespan. Bruce Mate, working with **Telonics, Inc.**, of Mesa, Arizona, designed and tested an umbrella stake attachment with curved tines that penetrated the skin about 7 cm and flared on entry. These VHF transmitters lay on the surface of the whale and were successfully used to track gray whales (Mate 1979). Mate (1980) also developed a similar barnacle radio tag **implantable** by bow or gun which was also tested successfully on gray whales. **Follmann** (1980) concurrently developed and tested a VHF radio tag with an attachment head that toggled approximately 2 inches under the skin and a transmitter and antenna that lay flat along the external surface of the animal. He was, however, unsuccessful in tracking with this system.

At the same time that investigators were first successfully radio tracking **small** cetaceans, **Craighead et al. (1972)** were testing a satellite-linked animal tracking device on free-ranging elk (**Cervus canadensis**). Although these first tests were hampered by the extreme size and **weight** of the transmitters and were generally thought to be unsuccessful, they led to a great deal of interest in the possibility of developing smaller, viable transmitters suitable for studies on animals as wide-ranging in size and habitat as birds and whales. A series of meetings during the late 1960's and early 1970's defined **at** great length the needs for satellite tracking, the technological **gaps** at that time, and the priorities for development (**Galler et al. 1972**; Anonymous 1974). However, it was not until the Fish and Wildlife Service (**Kolz et al. 1978**) successfully satellite tracked a polar bear (**Ursus maritimus**) for over one year and 1300 km that interest in satellite tracking was

revived. Based on that success, the National Marine Fisheries Service embarked upon the development of a satellite-linked transmitter (Jennings and Gandy 1980) for attachment to small cetaceans in the eastern tropical Pacific. This program has met with a number of problems, both electronic and biological, but successful tests are anticipated in 1981. Both the polar bear and the porpoise transmitters remain too large for general application to marine mammals.

Evaluation and discussion of radio tracking systems

There are currently three basic transmitting and receiving systems and four different types of radio transmitter attachments available for large cetaceans. Woodbridge (1978) discussed another potential animal tracking system using extra low frequencies (ELF), but its development and use on cetaceans is inadvisable due to excessive power requirements, large size, and possible interference with the whale's hearing and communication. Each of the other systems has its benefits and shortcomings and will be discussed in the following paragraphs.

High frequency (HF) systems (27-30MHz) - The greatest advantage of using high frequency systems for radio tracking at sea is the relatively great theoretical tracking distances attainable from shipboard because HF radio waves tend to follow the curvature of the earth and are not blocked by ocean waves. Another advantage is the availability of a relatively efficient ADF, an essential component of any operational radio tracking program. The major drawback to working at this frequency is the inefficiency of antennas which limits tracking range and, more importantly, necessitates larger radio tags because of the battery demands required to achieve adequate radiated power. Additionally, because

frequency scanners or other means of individual identification are not available at HF, multiple receivers are required to locate more than one transmitter.

The WHOI/OAR radio tag is currently the only attachment/deployment system available in the HF band. The maximum longevity of the latest iteration of this tag is unknown but there was no indication of rejection after nine days in the Iceland tests (Watkins 1981). The major advantage of the WHOI/OAR tag is the 30 m deployment range which makes it potentially useable on any species of large cetacean. Retuning of the antenna has solved some of the early problems of reduced range due to poor antenna orientation. Because of the differential movement of tissue layers through which these tags pass, the problems of continuous irritation and subsequent healing difficulties persist. Considerable practice and marksmanship are essential when using this tag system.

Very high frequency (VHF) systems (148-164 MHz) - Highly efficient antennas are available in this frequency range and the resultant low power requirements permit the use of very small, lightweight radio tags. Additionally, VHF scanning and data processing equipment have been developed to identify individual transmitters and collect telemetry data, and automated data collection and remote station capabilities are already being developed. Another advantage of the VHF frequency is the potential of less noise (the shorter ranges also provide fewer competing signals from a distance. There are, however, two drawbacks to using VHF for tracking at this time: 1) there is no ADF which will work effectively with the low power output from standard VHF transmitters, and 2) surface VHF reception is highly limited to line-of-sight and may be affected by

sea state. There is also some evidence that low-level inversions over cold water may block VHF propagation entirely for periods of time.

There are currently three possible attachment/deployment systems for VHF transmitters: the barnacle and umbrella stake tags developed by Bruce Mate and the whale tag developed by Erich Follmann. Each of these tags is small and lightweight, but because the transmitters lie on the surface of the whale, they are subject to dislodgement or crushing. The umbrella stake tag has the best antenna orientation of any tag available but attachment is restricted in use to quiescent whales. The barnacle tag can be deployed on moving whales but presently has limited deployment range (5 m in this study) and potentially poor antenna orientation. Although Follmann's tag is less liable to dislodgement and crushing than the other two tags and can be deployed at a greater distance (up to 9.1 m), very poor antenna orientation and detuning due to antenna contact with the whale severely limit the theoretical range of the transmitter in its present configuration. A fourth possibility for tracking whales in the VHF range would involve replacing the HF transmitter and antenna in the WHOI/OAR tag with a VHF transmitter and antenna.

Satellite systems (401.2MHz) - Satellite-linked systems can track animals and gather data over vast and inaccessible areas at relatively low cost. As fuel costs rise, this will be an ever increasing advantage over other tracking systems for long term or long distance studies. All satellite animal tracking to date has been accomplished using the Nimbus system, but since the system has passed its operational life expectancy, it is increasingly difficult to be assured of continued operation and reception priority. The newer Argos satellite system offers two location

and data collection satellites, sun-synchronous and polar orbiting which have good global coverage especially in the **higher** latitudes.

The **greatest** drawbacks to satellite tracking are that no tags are presently available for whales and that some **whale** species may not surface often enough during certain behavior modes to insure location by the orbiting receivers. Satellite tags should have a relatively **long** retention time to increase the probability of successful tracking.

In conclusion, it seems clear that the operational tracking of free-ranging large cetaceans is well within the realm of technological feasibility. The method of tagging and tracking will be dependent upon the objectives of a given study and upon the species to be studied. To insure operational systems, the following tests and developments are needed:

- 1) The development and testing **of** a VHF-AD)? for surface vessels and **aircraft**.

- 2) The development and testing of an automated data **collecton** unit with hard and soft copy capability for HF and VHF.

- 3) Inclusion of the automated data collection units in remote stations (capable of data storage for up to two weeks) for monitoring coastal species.

- 4) The development and testing of **HF** and VHF telemetry capability, initially for environmental monitoring (temperature and depth) followed by physiological monitoring (heart beat, blood pressure, core temperature).

- 5) The development and testing of a **high-gain, HF-ADF** antenna for aircraft.

6) Laboratory and field studies of rejection mechanisms designed to gather data which will suggest developments to increase longevity of tags.

7) The development and testing of an Argos satellite-linked location transmitter.

8) Continued development and testing of attachment mechanisms.

BOWHEAD WHALE TAGGING FEASIBILITY STUDY

Introduction

In June 1978 the Bureau of Land Management (BLM) of the U.S. Department of the Interior entered into an Endangered Species Section 7 consultation with the NMFS to determine the impact of oil and gas resource development in lease-sale areas of the Beaufort Sea on bowhead and gray whales. In August of that year, NMFS recommended studies to BLM that would fill the data gaps identified during the consultation. One type of study recommended was to determine the "timing of movements and offshore distribution of bowhead and gray whales through the proposed lease-sale areas and adjacent waters." Studying the "overall movement patterns of bowhead and gray whales in the Beaufort Sea" was also recommended by NMFS. Although the general pattern of migration is known for bowhead whales (Braham et al. 1980; Braham and Kroqman 1977; Fraker 1979; Fraker et al. 1978), the specifics of migratory timing, movements, and habitat use are largely unknown and lend themselves to study by radio tracking. With the successful tracking of radio tagged gray whales along their migratory path for up to 95 days (Mate 1979), a test was needed to determine the feasibility of tagging and tracking bowhead whales. In addition to determining the feasibility of finding, approaching, and tagging bowhead whales, this study sought to determine longevity of the

tags, effect of the tags on behavior, dive-surface profiles, and movement patterns of bowheads in the vicinity of the northern Alaska Outer Continental Shelf (**OCS**) lease-sale areas.

Study Area

For these initial tests a study area was chosen which would afford the maximum probability of **locating** bowhead whales in ice-free waters of the **Beaufort** Sea, where the animals could be approached **easily** by surface vessel and **tagged** without ice nearby **on** which the whales might dislodge the surface-mounted transmitters. It was also imperative to have an accessible logistical base with an airfield and supplies. After **studying whaling** and sighting records (**Bodfish** 1936; Cook 1926; **Fraker** and Bockstoce 1980; Hazard and **Cubbage** 1980; Ward 1979) and interviewing researchers who had worked in the Beaufort Sea (**H.W. Braham**, National Marine Mammal Laboratory, NMFS Northwest and Alaska Fisheries Center, Seattle, WA 98115; **M.A. Fraker**, LGL Ltd, Vancouver, B.C., Canada v6P 6G5; **D.E. Sergeant**, Arctic Biological Station, Fisheries and Marine Service, Ste. Anne de **Bellevue**, Quebec, Canada, H9X 3L6; and I. Stirling, Canadian Wildlife Service, Edmonton, Alberta, Canada, T5K 2J5. **Pers. commun.**) the **village** of Tuktoyaktuk was chosen as the logistical center because of the high probability of locating concentrations of whales between Cape Perry on the east and Herschel **Island** on the west. The relocation area encompassed the entire **Beaufort** Sea from approximately 125°W near Cape Perry, Northwest Territories, Canada, to 155°W near Point Barrow, Alaska, and offshore to approximately 72°N (Fig. 1). This area included the "north slope" OCS lease-sale area from 146°W to 154°W .

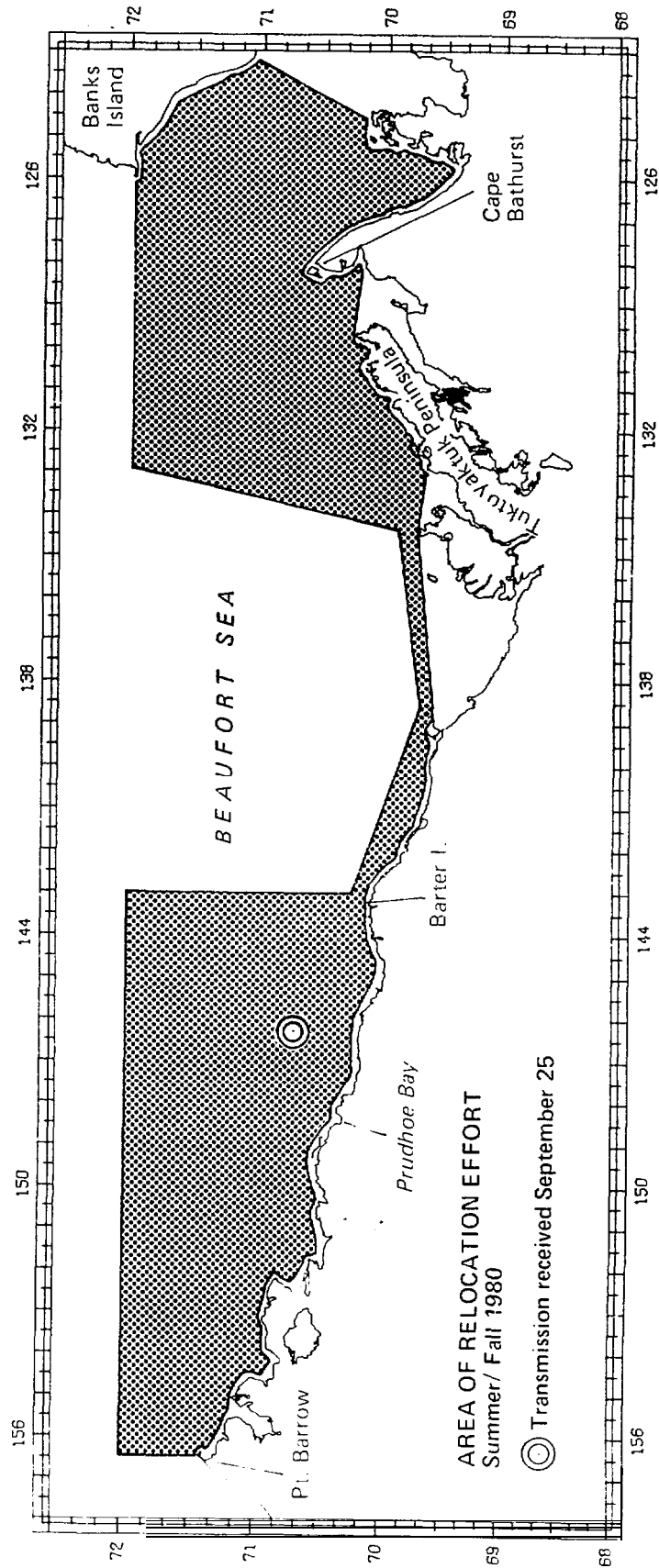


Figure 1. The bowhead whale tagging study area including the relocation effort during the summer/fall **1980**.

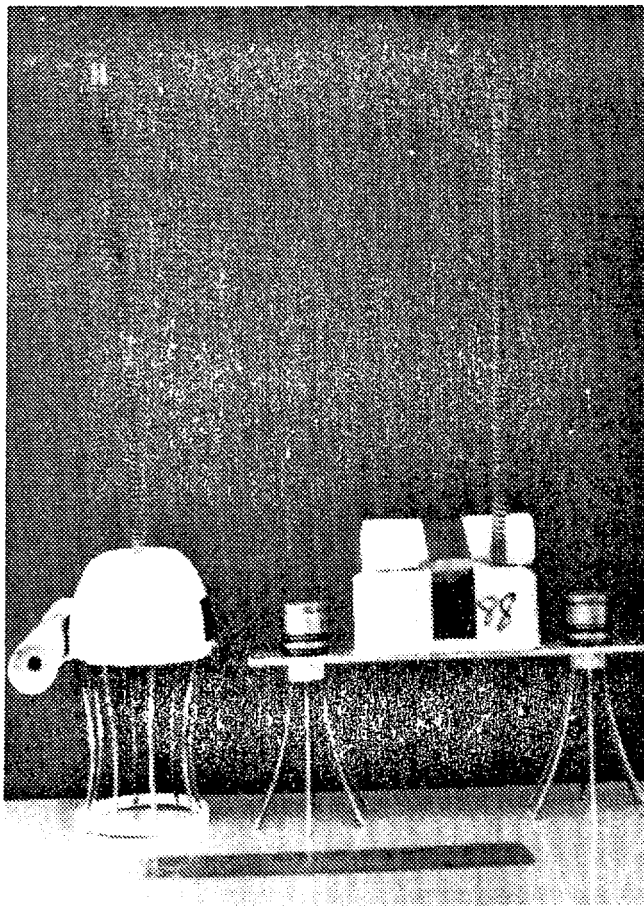


Figure 2 (top left)
Radio transmitter tags used for tagging
bowhead whales: barnacle tag, left;
umbrella stake tag, right.

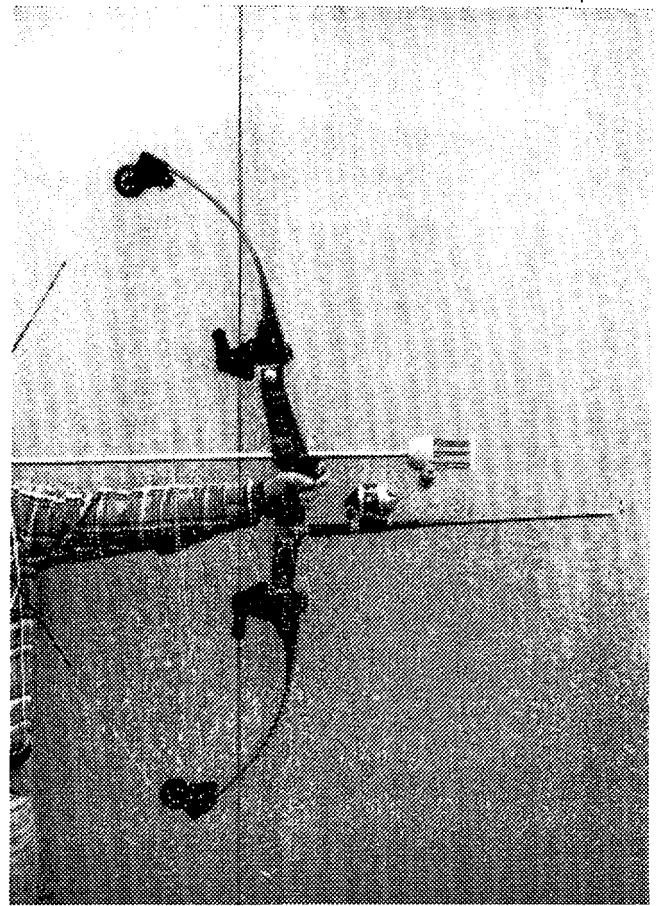


Figure 3 (bottom)
Modified drug immobilization rifle
used in deployment of barnacle tags.



Figure 4 (top right)
Compound bow equipped with a re-
trieval reel tested for use in deploy-
ment of barnacle tags.

Field Preparation

Of prime importance to this study was the testing, alteration, and fabrication of the radio tags. The tag types chosen for this experiment were developed and thoroughly field tested by Bruce Mate on gray whales (for description see Mate 1979 and Mate 1980). These barnacle and umbrella stake tags (Fig. 2) had, however, never been tested on any other cetacean species. Therefore, frozen blubber blankets were acquired from bowhead whales taken in the annual Eskimo harvest; and although the blubber samples did not accurately portray in vivo tissue responses, tests were undertaken to simulate the effects of the two tags on bowhead tissue and the effectiveness of the holdfasts relative to gray whale tissue.¹ The tags were tested and altered and retested over a 6 day period with the following results:

Barnacle tag - The maximum distance for proper deployment and antenna orientation of barnacle tags was initially calculated to be approximately 5 m. Thus, all test tags were fired from 5 m into the available pieces of bowhead blubber which included the fascia but not the skin and were extracted with a spring scale to give a relative indication of holding power of various test configurations. Video tape recordings were made of test firings to allow instant reevaluation. Initial tests showed that deployment by a drug immobilization rifle (Zulu Arms, Omaha, Nebraska; Fig. 3)² was superior in speed and accuracy to deployment by

¹ Special thanks for the blubber samples to Tom Albert, Erich Follman, Gordon Jarrell, and the Eskimo whaling captains who gave them tissues.

² Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

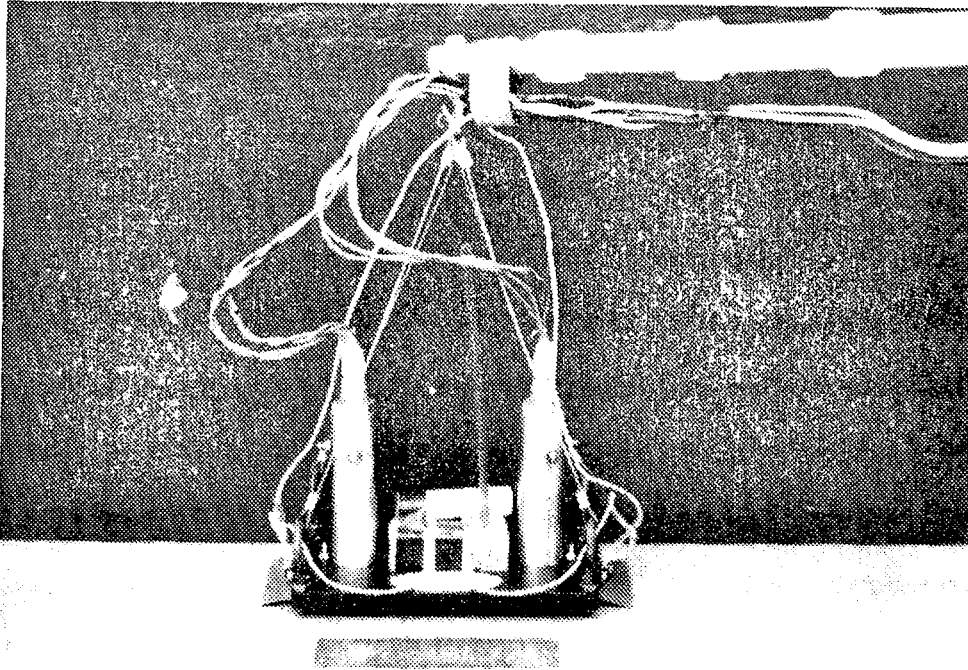


Figure 5
Module used for deploying
umbrella stake tags on
whales.

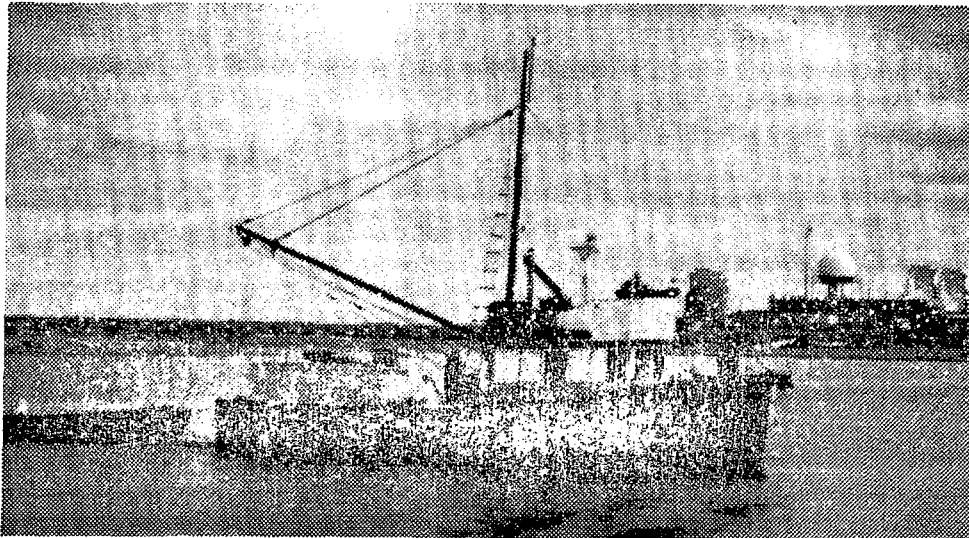


Figure 6
The *Pressure Ridge*, a 48
foot purse seiner, was used
by the tagging crew between
August 3 and August 19.

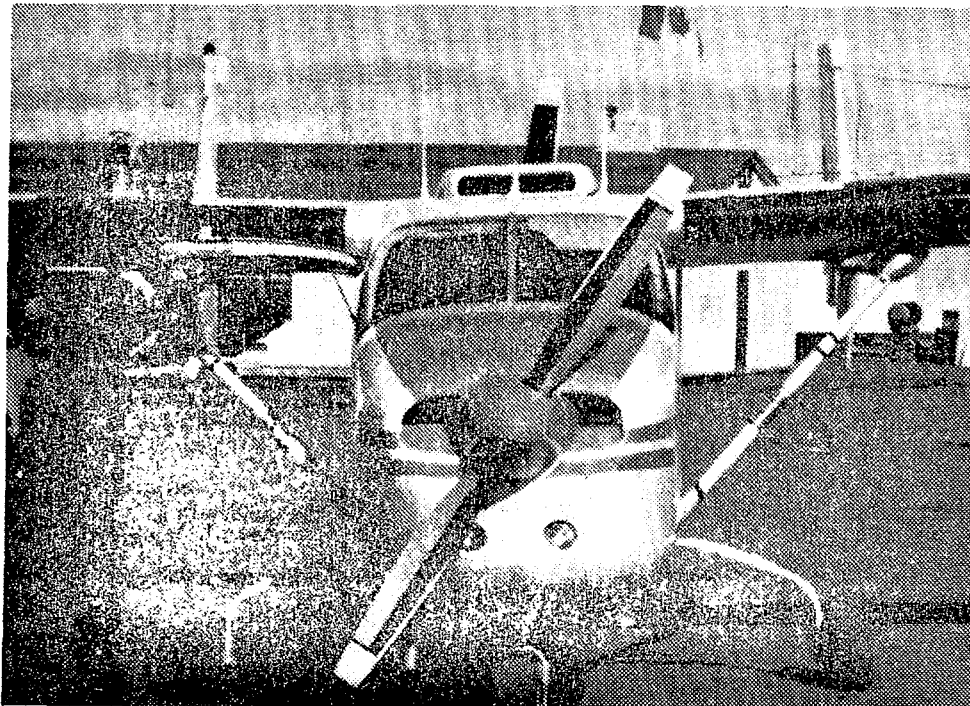


Figure 7
Charter aircraft used for
relocating tagged whales.
Receiving antennae were
easily mounted on wing
struts before flights.

a compound bow (Bear Archery, Gainesville, Florida; Fig. 4), and that the new teflon tine retaining rings worked well. They also suggested the following modifications and further tests: 1) place barbs on the tines to add greater holding power, 2) further deform tines before loading to create more flare, 3) file base of tines to help them further deform upon entry, and 4) dissect out shots to determine deformation in situ. Further test shots and dissection indicated that the addition of barbs and the further deformation of the tines before loading contributed significantly to the holding power of the tags and that filing the bases of the tines made no difference. Thus, the barnacle tags for the field experiments were fabricated with flaring tines, barbs, teflon retaining rings, 7.5 cm by 1 m Saflag visual streamers (Safety Flag co. of America) and the S2B5 transmitter and antenna (Telonics, Inc.) tested by Mate. The streamers were designed to aid in visual relocation and to provide a standard for determining the length of the tagged whale by aerial photogrammetry.

Umbrella stake tag - Early tests of this tag deployment system (see Fig. 5) indicated that the stakes were not seating against the base plate nor deforming when entering blowhead tissue as they had on gray whale tissue. These tests suggested the addition of barbs to the umbrella stake tines to increase holding power and further testing to determine if the stakes were not seating because of bounce back or because of lack of power for penetration. When barbs were added to the stake tines they uniformly seated on the baseplate and required well over twice

as much force to dislodge. Subsequently, barbs were added to all stakes for the field exercises.

The **receiving** system was identical to that used by Mate (Telonics TR-2 receiver, **TS-1** scanner, **TDP-2** processor, and **DF** receiver). However, rather than rely on individual frequencies for unique identification of each tagged animal and run the risk of missing a signal from a tag during a frequency scan, 15 transmitters were tuned to one frequency and the individual transmitter was identified by the time between pulses. The remaining three transmitters were tuned to another frequency and used as backups.

The success of the tagging project depended on our ability to find and approach bowhead whales at quite close range and then to radio track them from the surface and from the air. The 48 ft motor vessel, Pressure Ridge (Fig. 6) was chartered for the study. People familiar with bowhead whales in the Arctic (J. J. Burns, Alaska Department of Fish and Game, Fairbanks, AK 99701; R. Silook, Gambell, AK 99742; and V. Steen, Captain, Pressure Ridge, Tuktoyaktuk, Northwest Territories, Canada, XOE 1CO. Pers. commun.) felt that whales could be approached in an aluminum boat with outboard motor from the Pressure Ridge to within 5 m for tagging with the barnacle or umbrella stake tags. A 16 ft Lund Aluminum boat was purchased (and shipped to Tuktoyaktuk) with a variety of outboard motors and was modified for two sets of oars so that various methods of approach could be tested. A satellite navigation system was leased for Pressure Ridge to assure accuracy of sighting locations and vessel position.

A Grumman Goose, **N780**, already surveying for bowhead whales in the Beaufort Sea under contract to BLM, was modified to carry two, side-looking, high gain, two-element **yaqi** antennas and two whip antennas for direction finding (DF) capability. The Grumman N780 was made available periodically through the summer in the eastern Beaufort Sea and then again in the fall in the central and western Beaufort for reconnaissance and for radio **tag** relocation effort. In addition, removable mounts for side-looking, high gain antennas were fabricated for aircraft of opportunity and **small** charter aircraft (one set for high wing Cessnas (Fig. 7) and one set for Twin Otters).

In order to provide photodocumentation of the research and to provide the field party with a very useful tool for instantaneously evaluating research. protocol and **whale** behavior, a portable video tape unit was tested for field use. Video taped sequences could be used to compare normal bowhead behavior to the behavior of tagged whales, to document tag condition over time, and to record whale reaction to tagging. Still photos were taken of all phases of preparation and field activities.

Field Activities

Beginning 17 July, the Office of Aircraft Services of the U. S. Department of the Interior in **Anchorage** modified Grumman N780 for aerial radio **tracking**. After installation and testing of the antennae and receiving equipment in Anchorage, aerial surveys for bowhead whales were flown enroute to Tuktoyaktuk along the Alaska and Canadian Arctic coasts. Nine **gray** whale, six walrus (**Odobenus rosmarus**) and two white whale

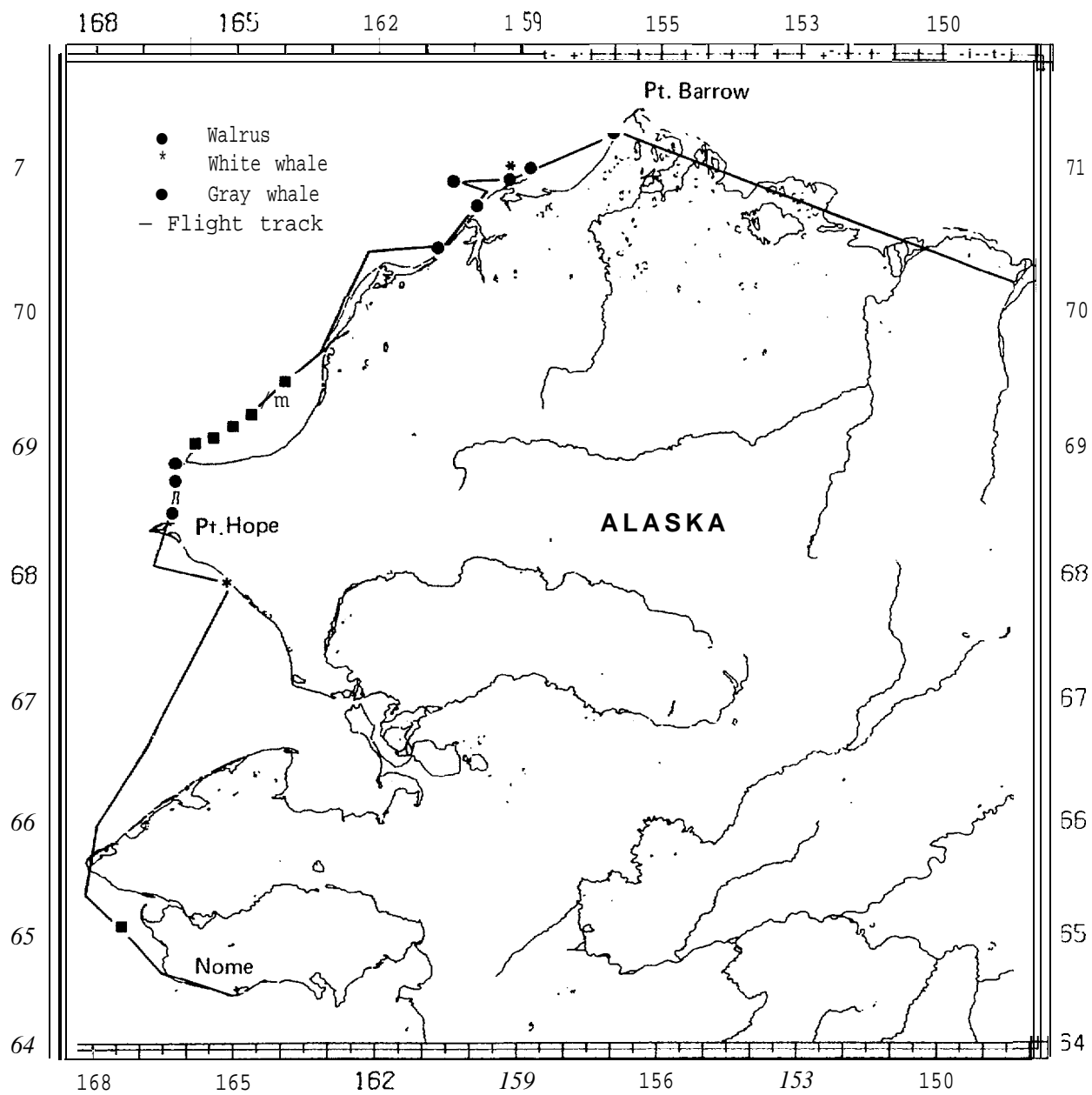


Figure 8. 20 July coastal survey from Nome to Point Barrow. No bowhead whales were sighted on this flight.*

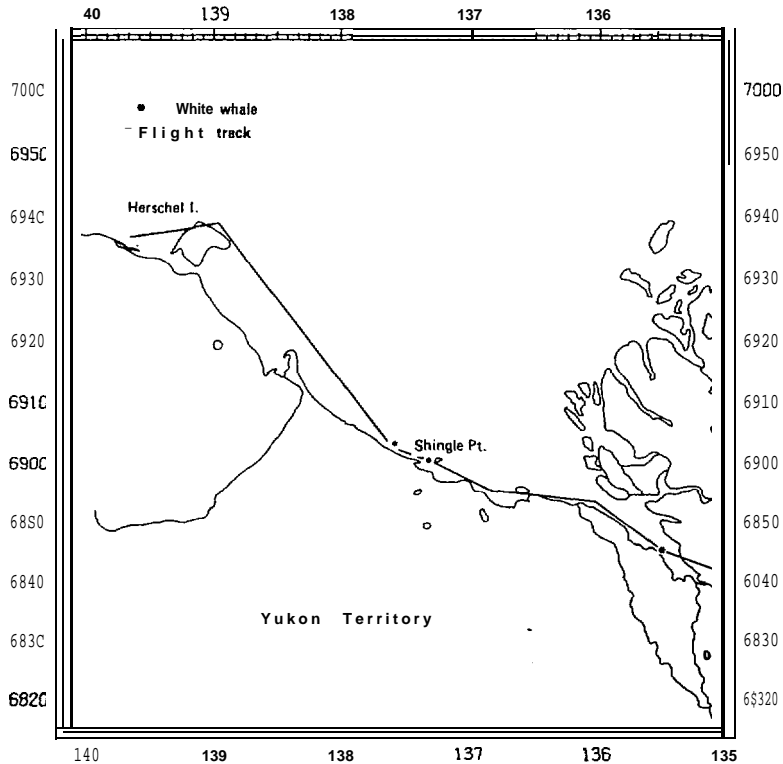


Figure 9. 21 July coastal survey from Herschel Island along the Yukon coast to the Mackenzie River. Hundreds of beluga whales were sighted in the vicinity of Shingle Point.*

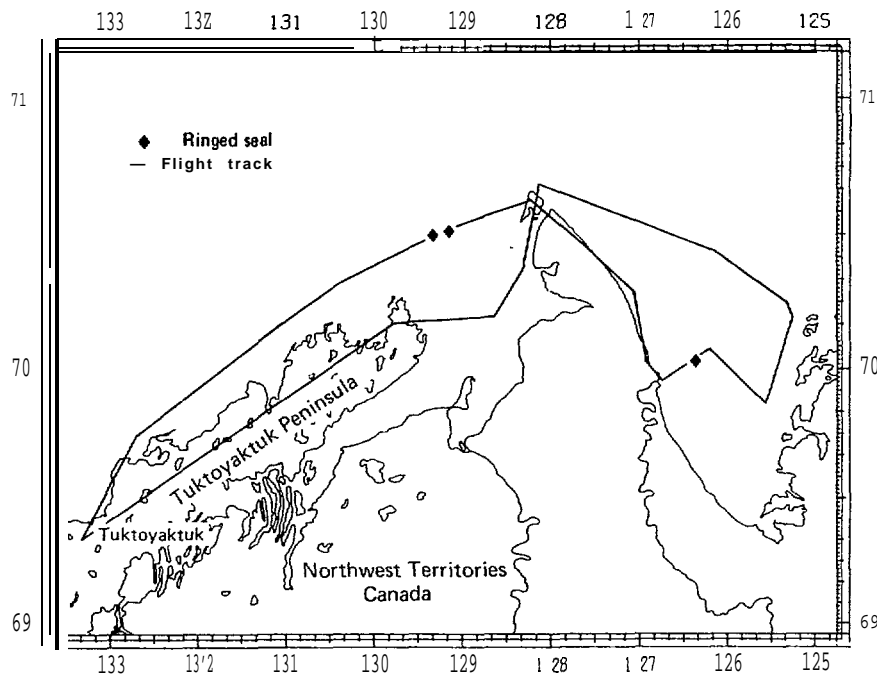


Figure 10. 22 July survey along the Tuktoyaktuk Peninsula into Liverpool and Franklin Bays. Note that no bowhead whales were sighted on this flight.*

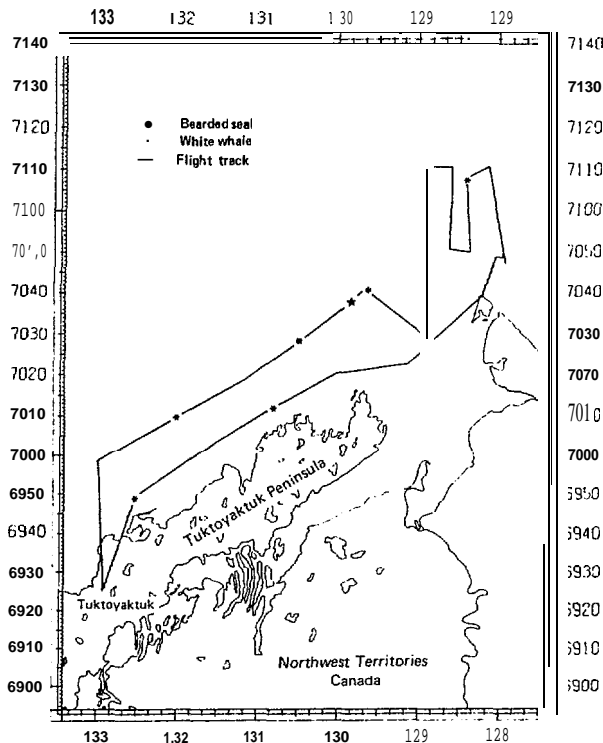


Figure 11. 23 July survey along the Tuktoyaktuk Peninsula and northwest of Baillie Islands—two areas of historical bowhead whale abundance in early August. [Unconfirmed bowhead sighting near beluga whale sighting at $70^{\circ}37.5'N$, $129^{\circ}50.6'W$.*

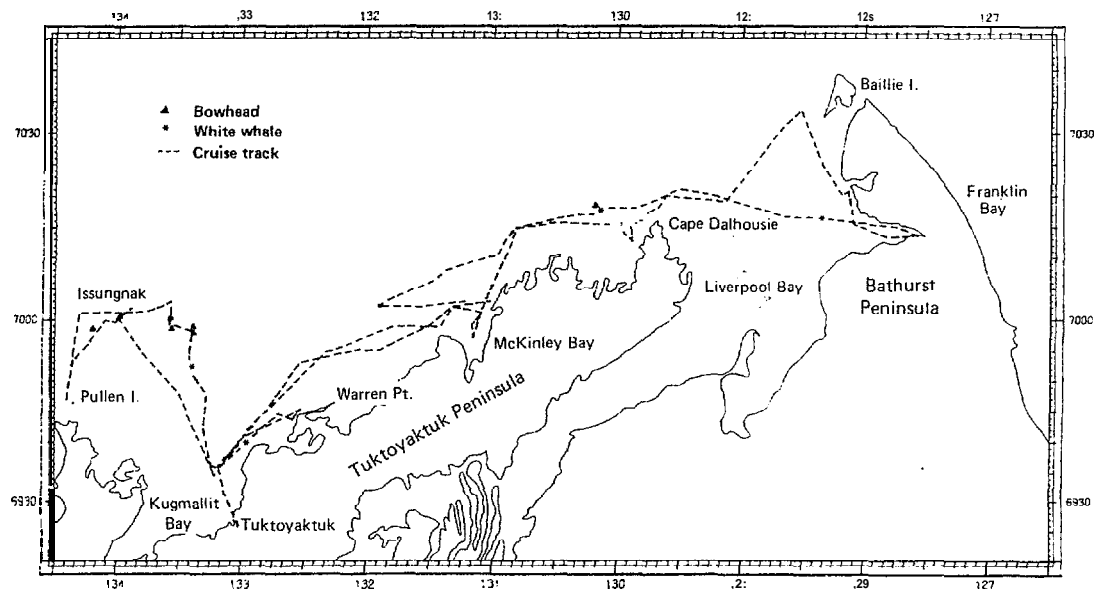


Figure 12. Cruise track of the Pressure Ridge from 3 August through 11 August, including sightings of bowhead and beluga whales. Areas to the east of Tuktoyaktuk were searched between 3 and 7 August and those to the west between 9 and 11 August. The bowhead sighting shown at $70^{\circ}18.0'N$, $130^{\circ}12.3'W$ was unconfirmed.%

(Delphinapterus leucas) sightings were made along the west coast of Alaska on July 20 (Fig. 8) and two large schools of white whales were sighted in Canadian coastal waters on July 21 (Fig. 9); no bowhead whales were sighted on either day of the survey. Further surveys were flown on 22 and 23 July to locate bowhead whale concentrations in the eastern Beaufort Sea. In 7 1/2 hours of flight along the Tuktoyaktuk Peninsula, Baillie Islands, and in Liverpool and Franklin Bays, only one possible sighting of a single bowhead (70°37.5'N, 129°50.6'W) was made in addition to four sightings of ringed and bearded seals and six sightings of 33 white whales moving predominantly southwest toward the Mackenzie River Delta (Figs. 10, 11). Before Grumman N780 returned to Alaska on 24 July, all radio receiving systems were tested and calibrated, and the survey crew was given instructions in the use and care of the aircraft receiving equipment.

On August 3 the charter vessel, Pressure Ridge, left Tuktoyaktuk Harbor completely outfitted for 15 days at sea, searched for bowhead whales reported along the Tuktoyaktuk Peninsula and then continued on to the vicinity of Baillie Islands where whaling records indicated the abundant occurrence of whales in early August (Fraker and Bockstoe 1980). The scientific party spent 4 days searching as far east as Franklin Bay and recorded only one unconfirmed bowhead whale sighting along with 2 sightings of ringed seals (51 animals) and 4 sightings of bearded seals (4 animals) (Fig. 12).

The Pressure Ridge returned to Tuktoyaktuk to solve radio communication problems and to determine the location of whale concentrations reported by Mark Fraker ("Effects of Human Disturbance" study, LGL, Ltd.). Between 9 and 11 August a total of 34 bowhead whales

were encountered on 5 occasions and in 2 cases tagging was attempted and abandoned after a short time because of heavy fog (Fig. 13). A school of about 70 white whales was sighted on 9 August heading west toward the McKinley Delta. Bowhead whales encountered during this time were moving quite rapidly and could only be tagged with the ballistically deployed barnacle attachment, since umbrella stake tags can only be attached to relatively sedentary whales. Bowheads were approached in the aluminum skiff at high speed as was advised by native hunters, but each time the skiff came within about 30 m, the whales sounded. In no instance was it possible to maneuver within tagging distance. Four weather then forced the Pressure Ridge back to Tuktoyaktuk Harbor on 11 August. .

On 13 August Grumman N780 returned to Tuktoyaktuk to survey the nearshore waters and to determine the distribution of whales. In 22 sightings 30 whales were counted between Warren Point and Cape Dalhousie (Fig. 13) during systematic surveys flown parallel to the Tuktoyaktuk Peninsula on 14 August. Subsequently, survey and search flights were flown (Figs. 14-23; Table 1) to determine any change in distribution and to direct the tagging team to areas of maximum whale concentration. While in Tuktoyaktuk awaiting good weather, a barnacle tag was tested on a white whale killed in the Eskimo fishery. The tag deployed very well and is recommended for radio attachment for that species.

Bad weather conditions prevented any work from the Pressure Ridge between 16 and 19 August. The aircraft survey crew made 88 sightings of 161 bowhead whales during this time (Figs. 14, 15). On 19 August the vessel charter was terminated by mutual agreement and the tagging team

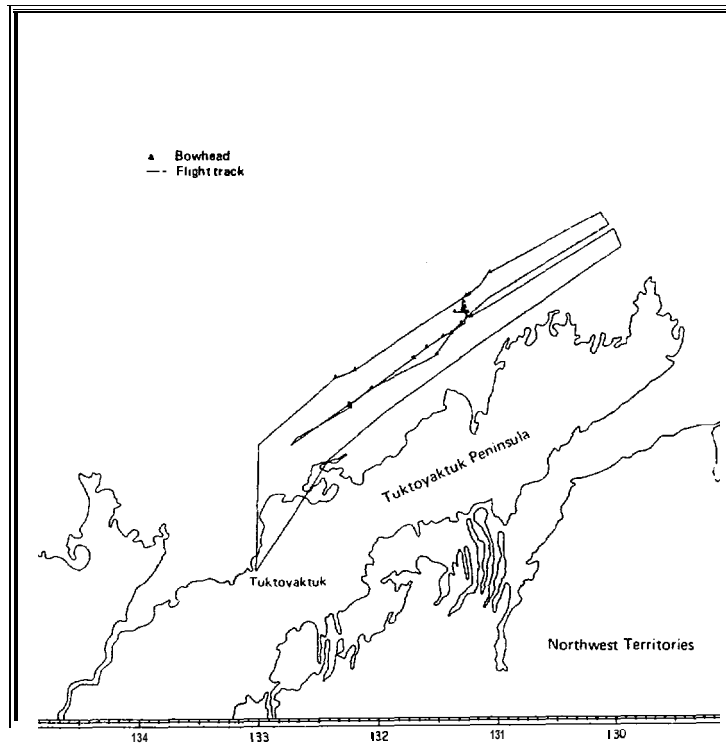


Figure 13. The 14 August survey flown in the Grumman Goose. There were 22 sightings of 30 bowhead whales on this flight.

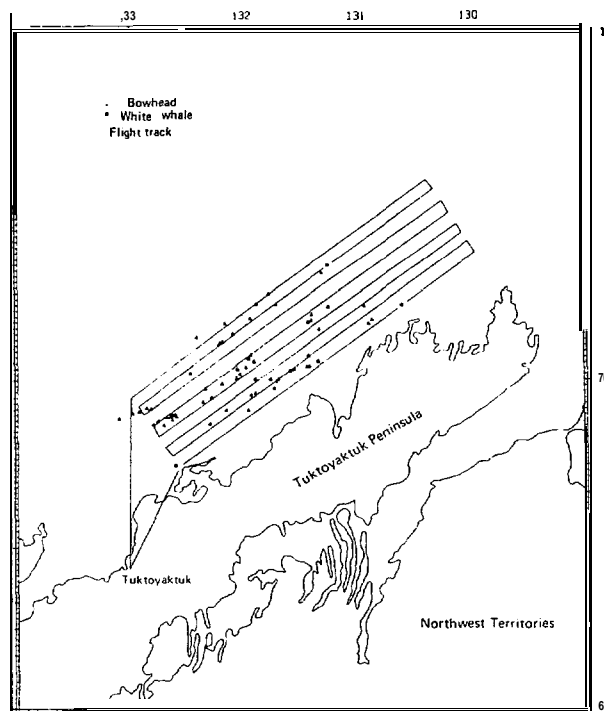


Figure 14. 18 August aerial survey along the Tuktovaktuk Peninsula resulted in 28 sightings of 47 bowheads.

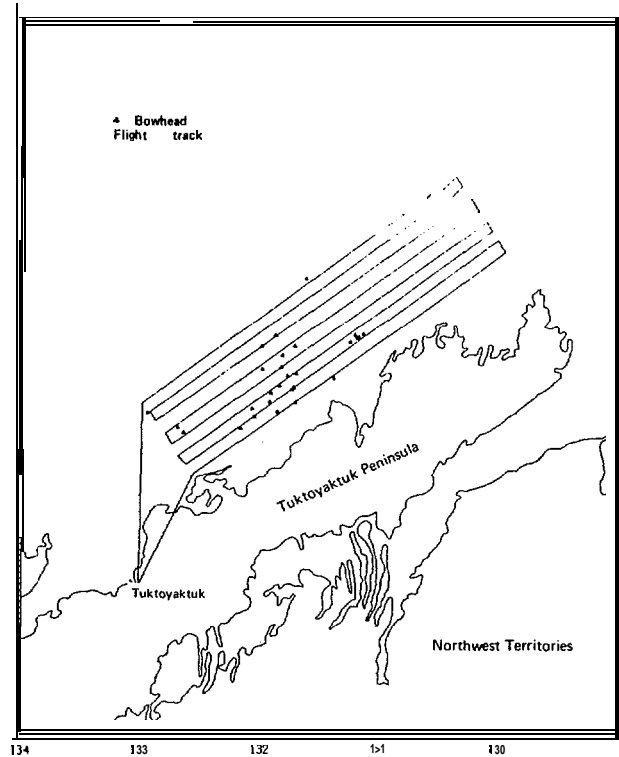


Figure 15. 19 August aerial survey logged 60 sightings of 114 bowheads and 14 belugas in three sightings.

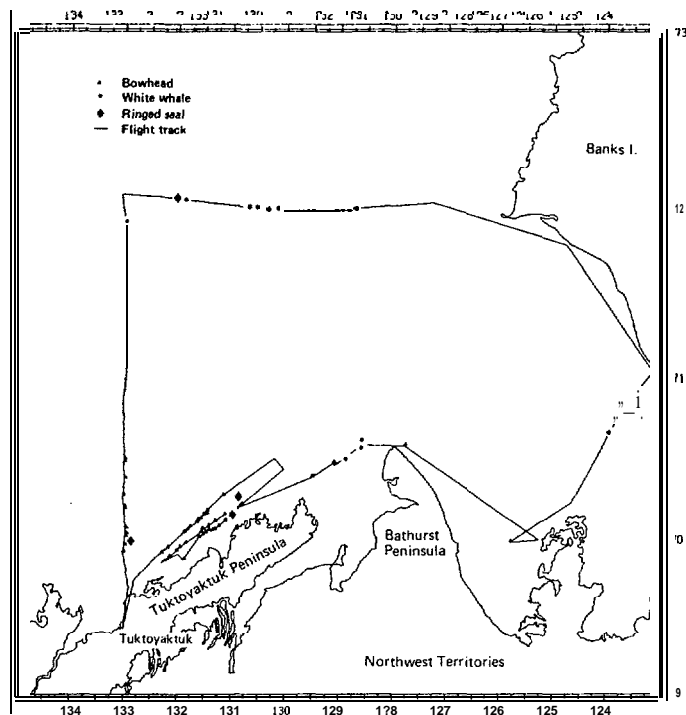


Figure 16. 20 August aerial survey designed to determine the distribution of bowheads in open water of the eastern Beaufort Sea. There were 46 sightings of 157 bowheads, 18 sightings of 194 beluga, and four sightings of five ringed seals on this flight.

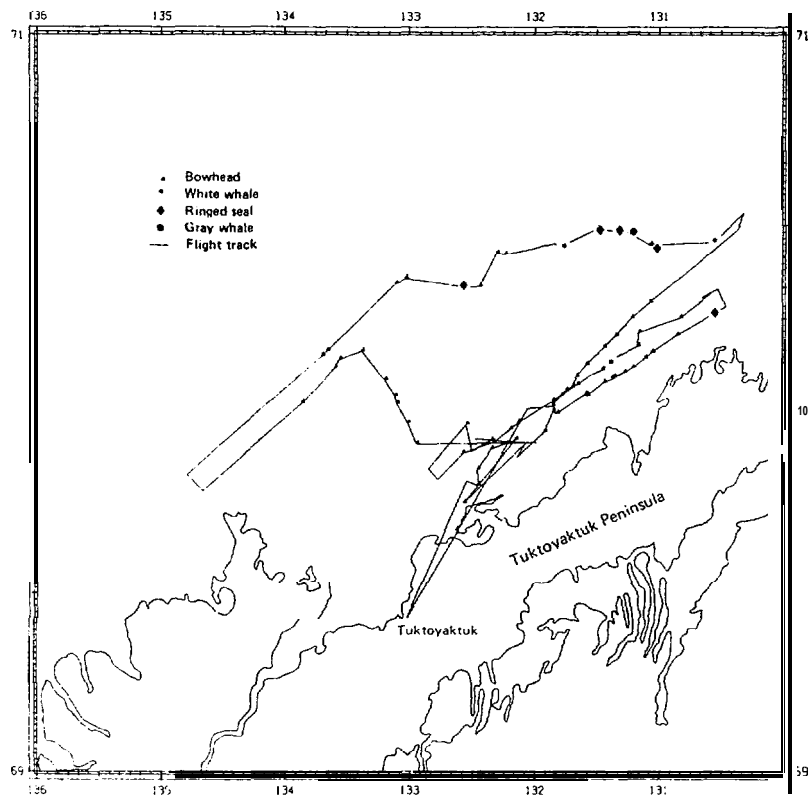


Figure 17. 21 August survey along the Tuktoyaktuk Peninsula showing the distribution of 59 sightings of 245 bowheads, three sightings of 49 belugas, six sightings of 113 ringed seals, and one gray whale sighting. Tagged bowhead number 137 was monitored for 1 1/2 h by the Grumman Goose before returning to Tuktoyaktuk for fuel.

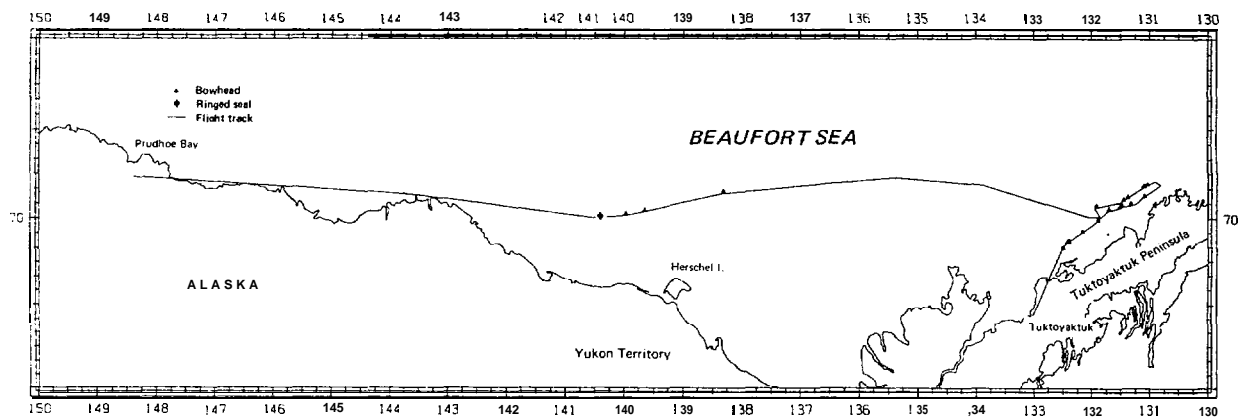


Figure 18. On 22 August, sixteen sightings of 73 bowheads were made along the Tuktoyaktuk Peninsula and three sightings of 12 whales were made en route to Deadhorse, Alaska.

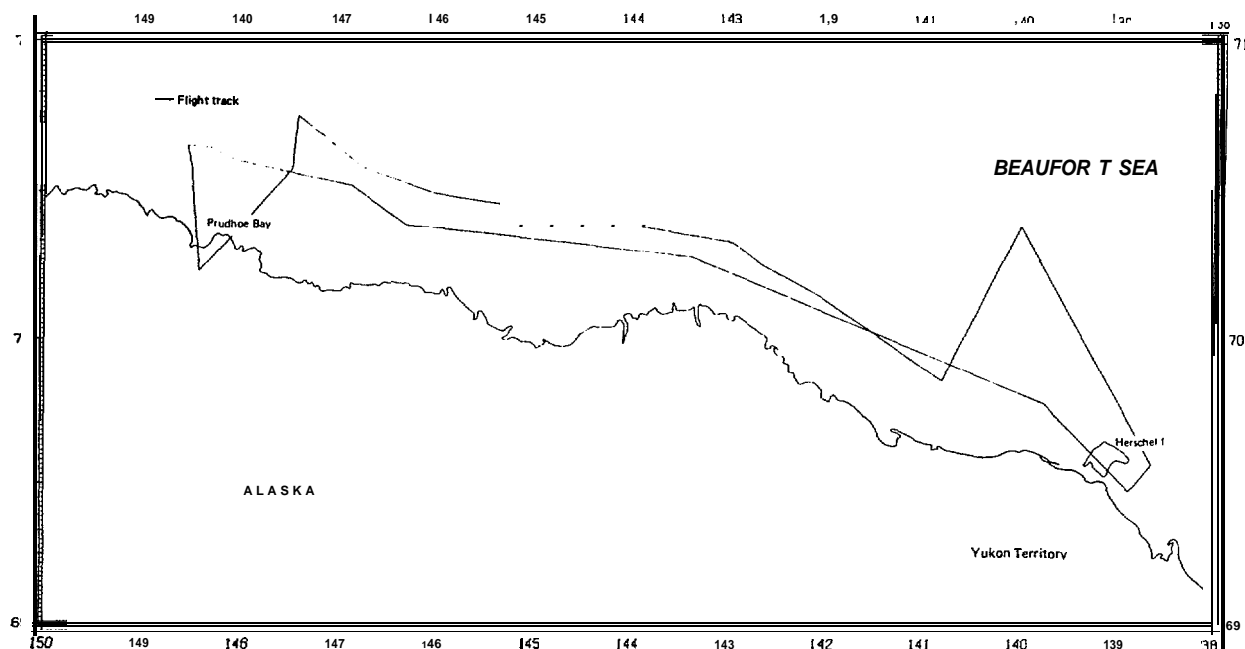


Figure 19. 30 August survey along the Alaskan and Yukon Coasts. Deteriorating weather conditions prevented surveying efforts to continue east to Tuktoyaktuk. No whales were sighted between Prudhoe Bay and Herschel Island.

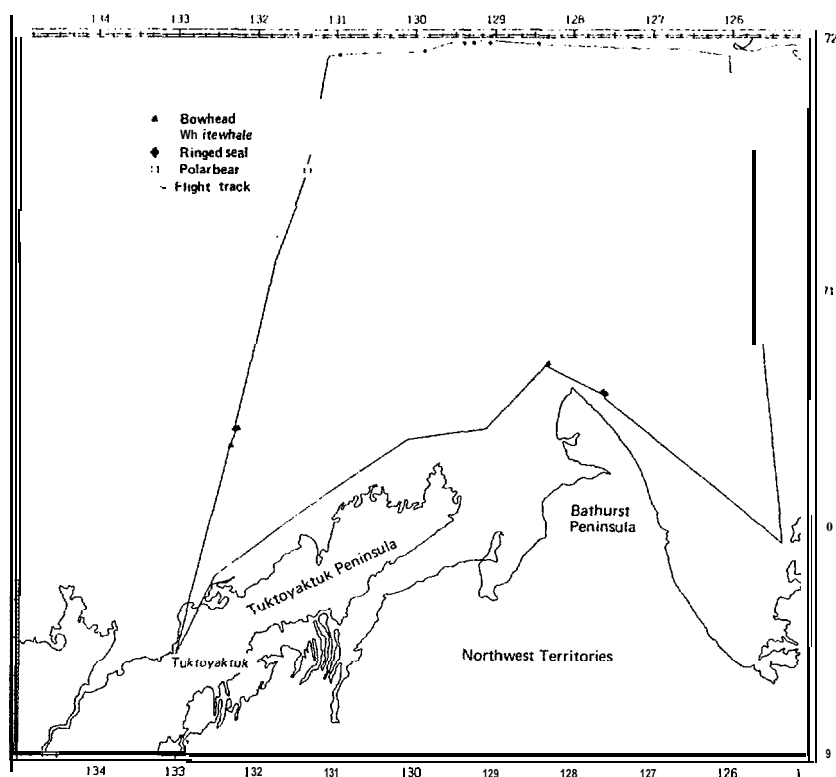


Figure 20. Broad area covered by 31 August survey of the eastern Beaufort Sea and Amundsen Gulf in an attempt to define fall bowhead distribution and relocate tagged whales. There were six sightings of 12 bowheads, seven sightings of at least 23 belugas, and one polar bear sighting.

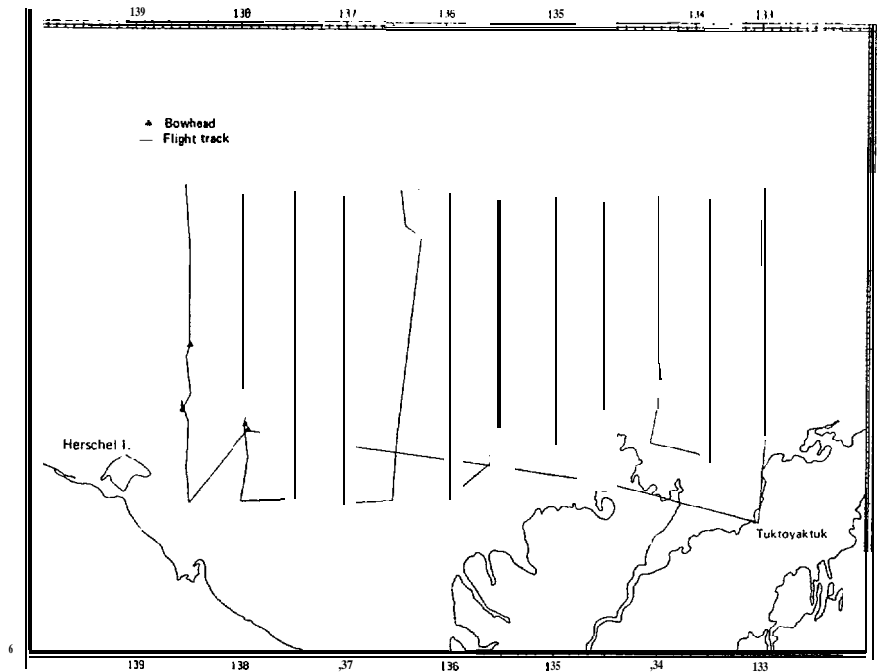


Figure 21. 3 September survey and radio tag relocation flight north of the Mackenzie Delta from the Tuktoyaktuk Peninsula to Herschel Island. Four sightings of eight bowheads were made on this flight.

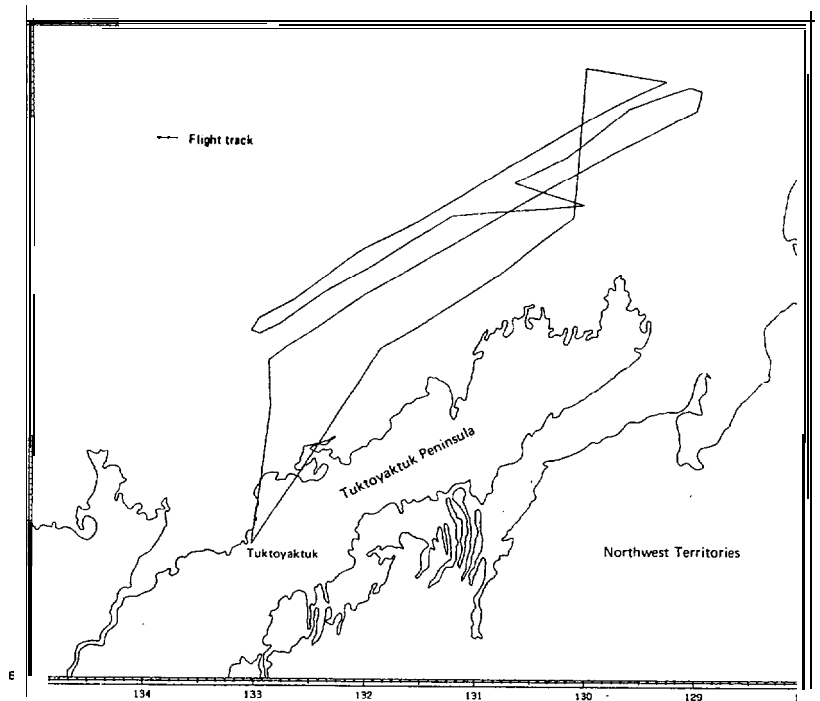


Figure 22. 4 September survey off the Tuktoyaktuk Peninsula searching for whale concentrations and radio tagged whales. No whales were sighted.

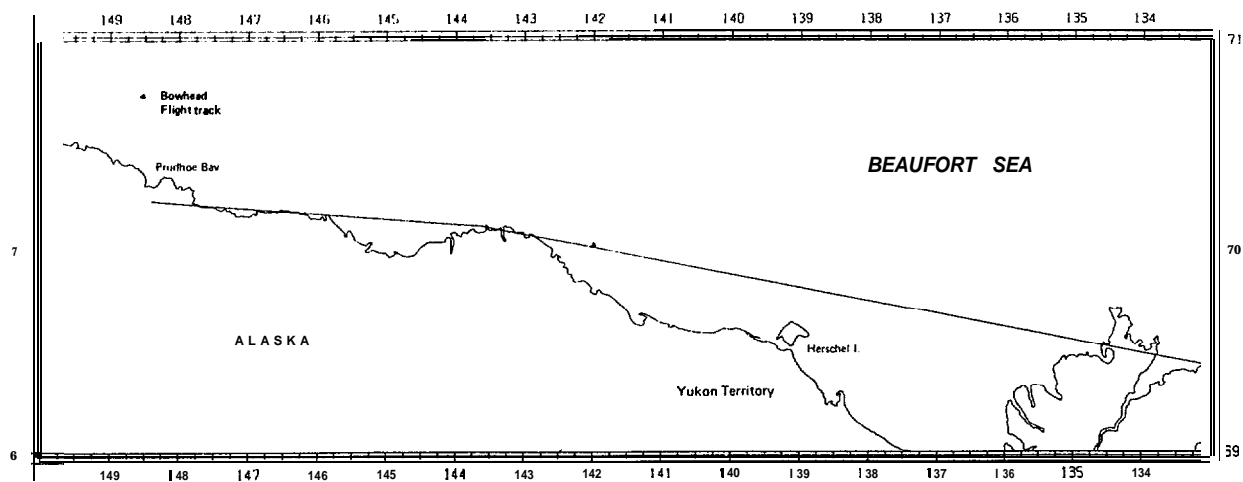


Figure 23. 4 September survey from Tukttoyaktuk to Prudhoe Bay, Alaska. There was one sighting of two bowheads.

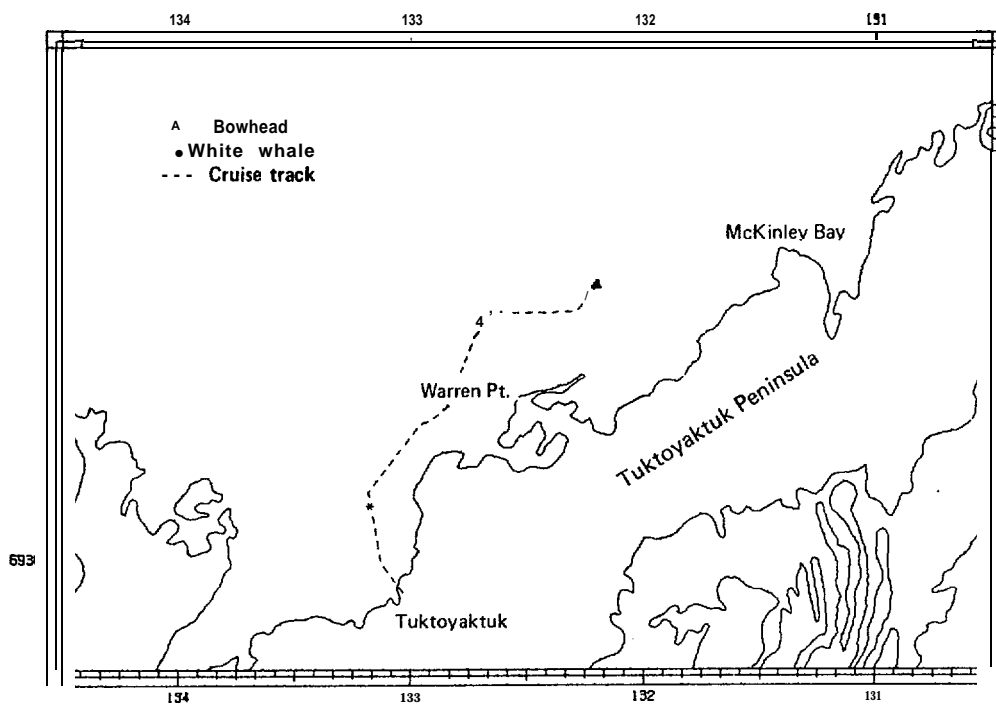


Figure 24. 20 August cruise track of the Ungaluk. Tag number 135 was successfully deployed at $69^{\circ}54'N$, $132^{\circ}12'W$.*

TABLE 1.--Sighting data collected by aircraft and shipboard observers in the eastern Bering Sea between 3 August and 12 September 1980.

Date	Platform	Species ¹	Number of Sightings	Number of Animals	Mean Size	Group \pm S.D.
August 3	Pressure Ridge	BE	1	1	1	\pm 0
		RS	1	50	50	\pm 0
		BS	2	2	1	\pm 0
August 4	Pressure Ridge	BO	1	1	1	\pm 0
		BE	2	2	1	\pm 0
		BS	1	1	1	\pm 0
August 5	Pressure Ridge		0			
August 6	Pressure Ridge	RS	1	1	1	\pm 0
		BS	1	1	1	\pm 0
August 7	Pressure Ridge		0			
August 9	Pressure Ridge	BO	3	24	8	\pm 10.4
		BE	1	70	70	\pm 0
August 10	Pressure Ridge	BO	1	1	1	\pm 0
August 11	Pressure Ridge	BO	1	9	9	\pm 0
August 14	Grumman N780	BO	22	30	1.36	\pm 0.95
August 16	Pressure Ridge		0			
August 18	Grumman N780	BO	28	47	1.68	\pm 1.02
August 19	Grumman N780	Bo	60	114	1.90	\pm 1.27
		BE	3	14	4.67	\pm 1.53
August 19	Pressure Ridge		0			
August 20	Grumman N780	BO	46	157	3.41	\pm 4.95
		BE	18	194	10.78	\pm 12.95
		RS	4	5	1.25	\pm 0.50
August 20	Ungaluk	BO	2	32	16.00	\pm 5.66
		BE	1	1	1	\pm 0
		RS	7	13	1.86	\pm 2.27
August 21	Grumman N780	BO	59	245	4.15	\pm 4.98
		BE	3	49	16.33	\pm 22.37
		GW	1	1	1	\pm 0
		RS	6	113	18.83	\pm 15.38

TABLE 1.--Sighting data collected by aircraft and shipboard observers in the eastern Bering Sea between 3 August and 12 September 1980--continued.

Date	Platform	Species ¹	Number of Sightings	Number of Animals	Mean Size	Group \pm S.D.
August 21	Ungaluk	BO	92	193	2.10	\pm 3.40
		RS	15	36	2.40	\pm 1.68
August 22	Grumman N780	Bo	19	85	4.47	\pm 5.10
		as	1	9	9	\pm 0
August 22	Ungaluk	BO	69	92	1.33	\pm 0.82
		RS	23	24	1.04	\pm 0*21
August 23	Ungaluk	BO	5	20	4.00	\pm 6.71
		RS	18	23	1.28	\pm 0.57
August 24	Ungaluk	BO	26	30	1.15	\pm 0.37
		BE	1	10	10	\pm 0
		RS	9	11	1*22	\pm 0.44
August 31	Grumman N780	BO	6	12	2.00	\pm 1.10
		BE	7	23	3.27	\pm 2.14
		PB	1	1	1	\pm 0
Sept. 3	Grumman N780	BO	4	8	2.00	\pm 0.82
Sept. 4	Grumman N780	BO	1	2	2	\pm 0
Sept. 12	Skymaster	BO	25	37	1.48	\pm 0.82
		BE	3	17	5.67	\pm 8.08
		RS	2	51	25.50	\pm 34.65
		Bs	1	1	1	\pm 0
		PB	1	1	1	\pm 0

- ¹ BO = Bowhead Whale
 BE = White Whale
 GW = Gray Whale
 RS = Ringed Seal
 BS = Bearded Seal
 PB = Polar Bear

transferred from Pressure Ridge to a shared charter with an NMFS research team aboard the sailing vessel Ungaluk.

During the afternoon of 20 August, whales were sighted from the Ungaluk in the vicinity of Warren Point along the Tuktoyaktuk Peninsula (Fig. 24) and tagging was attempted from the aluminum boat, **again** using the outboard motor. Various approach angles and speeds were tested but only one approach came near firing range (about 10 m), and the shot taken with a barnacle tag fell **well** short of the whale. After 3 hours, fog closed in and further tagging attempts were only possible from the Ungaluk. Quiet approach by sail worked well and at 2330 hours (**69°54'N, 132°12'W**) barnacle tag number 135 with a white streamer was placed on a 35 ft **bowhead** (Fig. 25). The **animal** had rolled on its side and the transmitter was implanted midway down the left upper body, too **low** for transmission on each **surfacing**. When tagged, the whale kept rolling in its sounding dive without changing speed or thrashing flukes. Signals were received intermittently for 10 minutes and then lost.

Because of the successful **tag** placement under sail, it was decided to attempt further quiet approaches by rowing the aluminum boat rather than using the motor. On 21 August (for CrUiSe track see Fig. 26) barnacle tag number 137 with a yellow streamer was successfully placed on a 40 ft bowhead whale using the rowing technique (Fig. 25). After the tag implanted, the whale continued to lay at the surface for about 4 seconds, twitched its skin, and **slowly** swam away. Grumman N780 was surveying in the area (Fig. 20) and was able to receive signals from the **tagged** animal until it ran low on fuel, about 1 1/2 hours after initial radio contact. The dive-surface data collected at that time from tag number 137 (Fig. 27) was contaminated to an unknown extent by radio

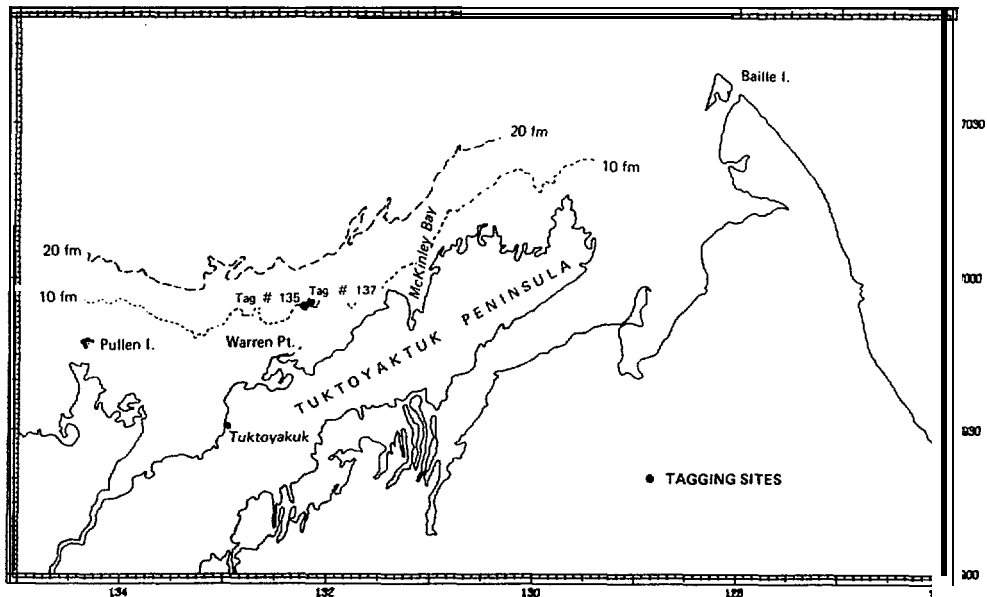


Figure 25. Two bowhead whales were tagged during this study: transmitter number 135 was deployed on 20 August ($69^{\circ}54'N$, $132^{\circ}12'W$) followed by transmitter number 137 on 21 August ($69^{\circ}55'N$, $132^{\circ}11'W$).

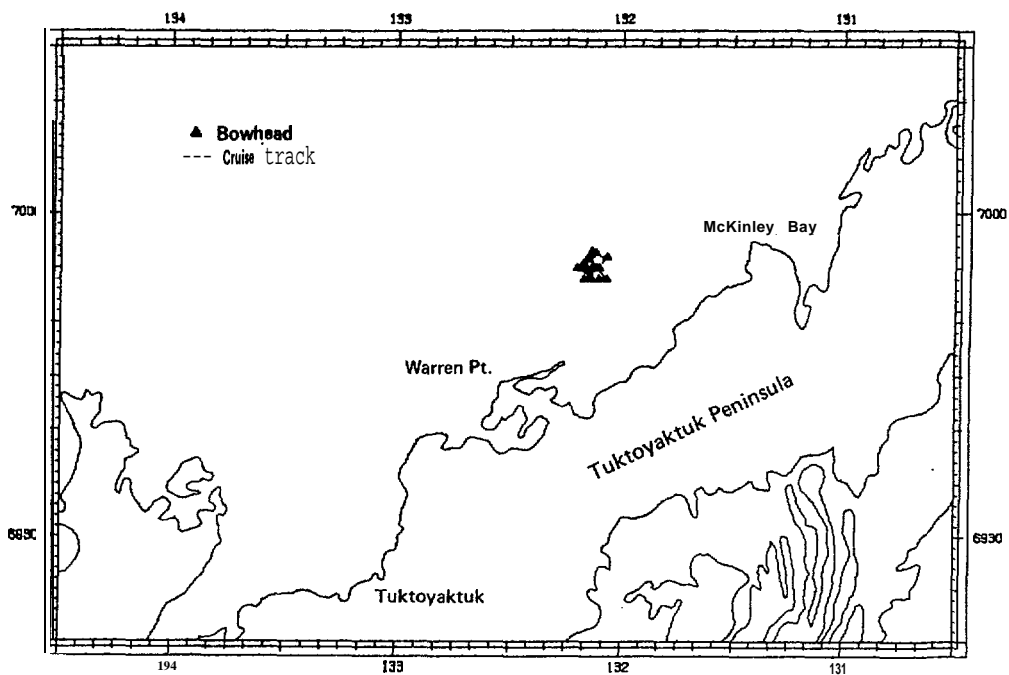


Figure 26. 21 August cruise track of the Ungaluk. Tag number 137 was successfully deployed at $69^{\circ}54'N$, $132^{\circ}11'W$.*

INSTRUMENTED AND NON. INSTRUMENTED WHALE SURFACINGS

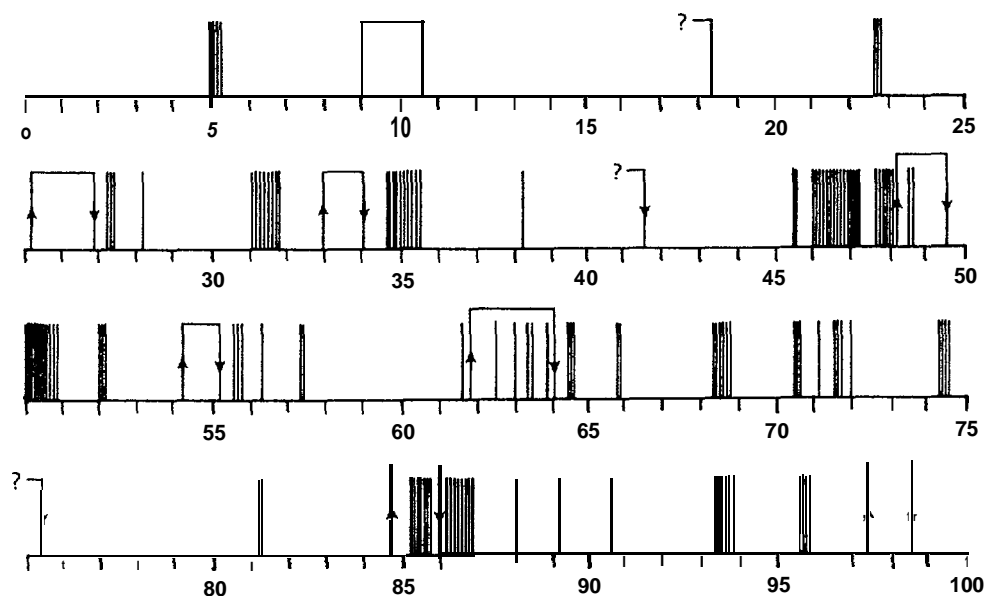


Figure 27. Each single line represents a signal acquired by aircraft from radio tagged whale #137 and lines with arrows represent the dive/surface pattern of a bowhead recognizable from natural markings. Two tags may have been transmitting during this period. Time is indicated along the horizontal axis in minutes.

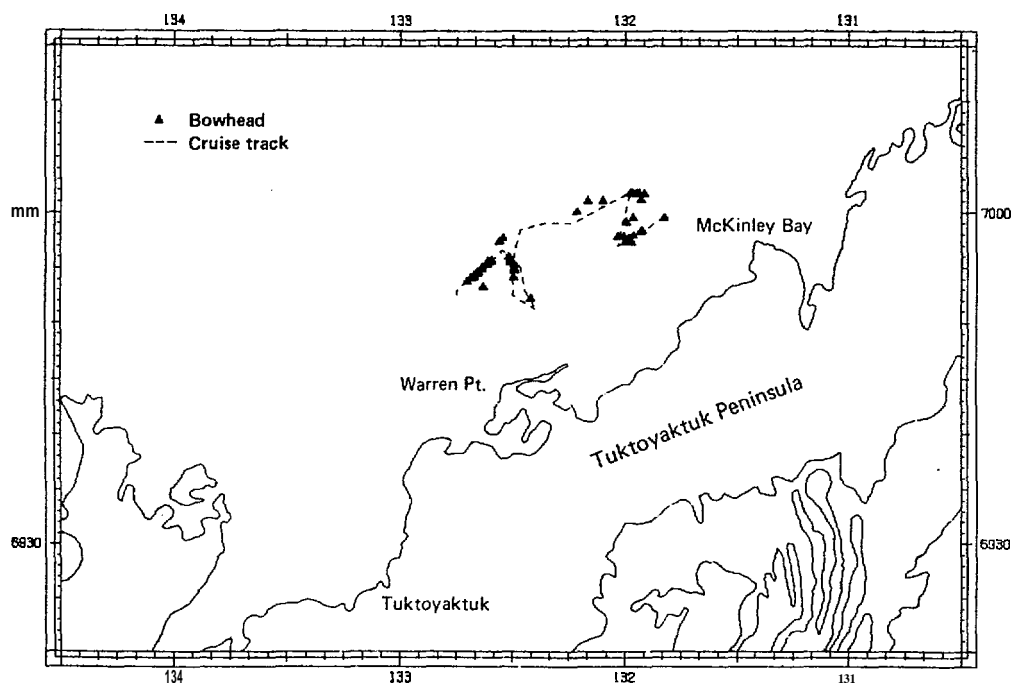


Figure 28. 22 August cruise track and sightings from Ungaluk. Each symbol represents one sighting of one or more animals.

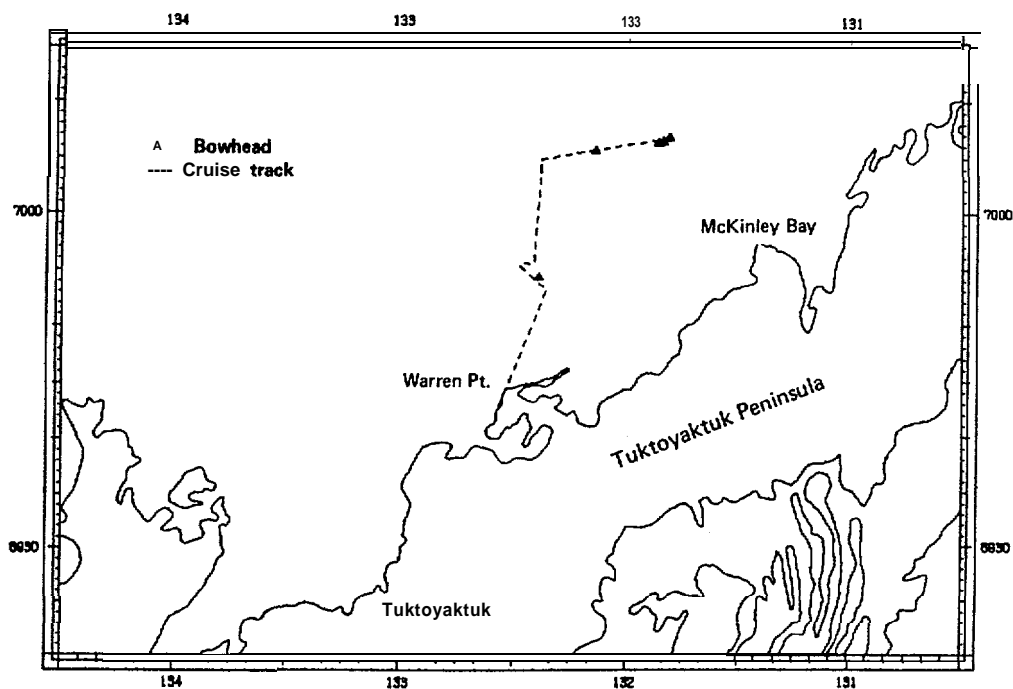


Figure 29. 23 August cruise track and sightings from Ungaluk.
Each symbol represents one sighting of one or more animals.

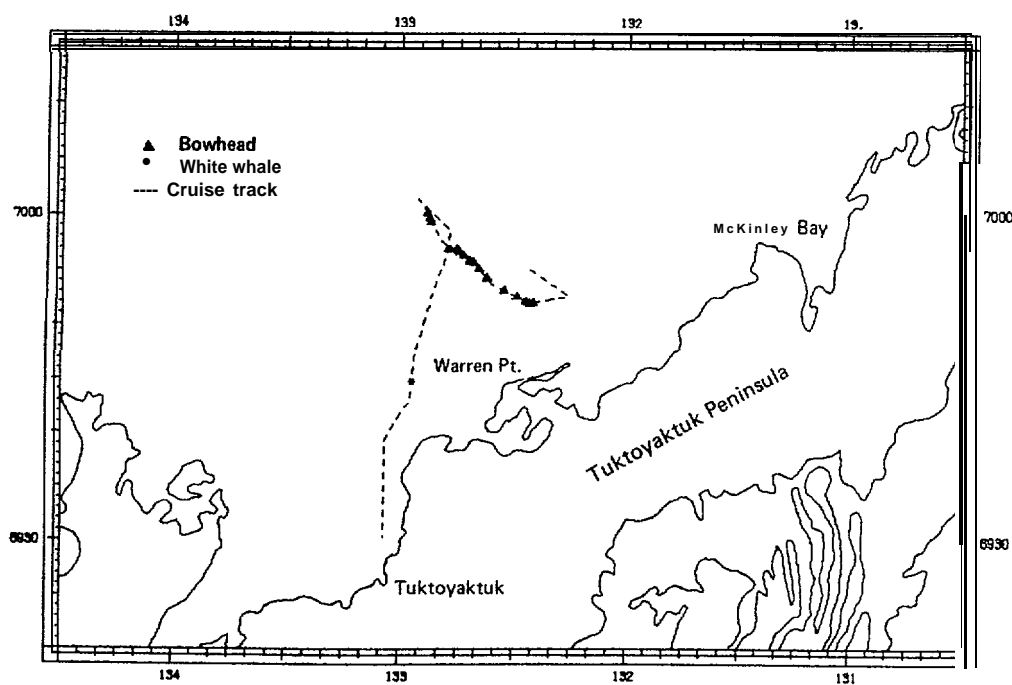


Figure 30. 24 August cruise track and sightings from Ungaluk.
Each symbol represents one sighting of one or more animals.

transmissions at the same frequency from Ungaluk and the tagging skiff. The receiving range from the Ungaluk, which should have been 15 miles, had deteriorated since previous tests to less than 2 miles; and by the time faulty antenna connectors were identified and repaired, the whale had disappeared and signals were not received **again**. Later that day, a barnacle tag shot missed a bowhead at close range. There was no visible reaction to the discharge or to the tag striking the water about 2 m beyond the whale.

On 22 August the aerial survey team searched for the tagged whales and then returned to Alaska. For the next 3 days (Figs. 28-30), the scientific party aboard Ungaluk searched for large concentrations of whales but the bowheads seemed to be spreading out and **moving** west rapidly. One group of juvenile whales (approximately 30 ft in length) surfaced repeatedly **within** about 50 m of the aluminum boat, but the skiff was too heavy and awkward to be rowed fast enough to reach them before sounding. However, dive-surface profiles were collected from animals identifiable by natural scar patterns, and one profile was compared to the radio transmissions from tag number 137 (Fig. 27).

Although large numbers of whales were seen along the Tuktoyaktuk Peninsula between 25 and 27 August by LGL and NMFS scientists, the Ungaluk, which had run aground on 25 **August**, was unfit to return to sea. On 30 August the aerial survey team attempted to fly to Tuktoyaktuk but was forced to return to Deadhorse because of weather. No whales were sighted on that flight between Prudhoe Bay and Herschel Island (Fig. 19). Surveys conducted aboard Grumman N780 on 31 August and 3 and 4 September indicated that bowhead whales had dispersed from the Tuktoyaktuk Peninsula (Figs. 20-23) and no large concentrations were found (10

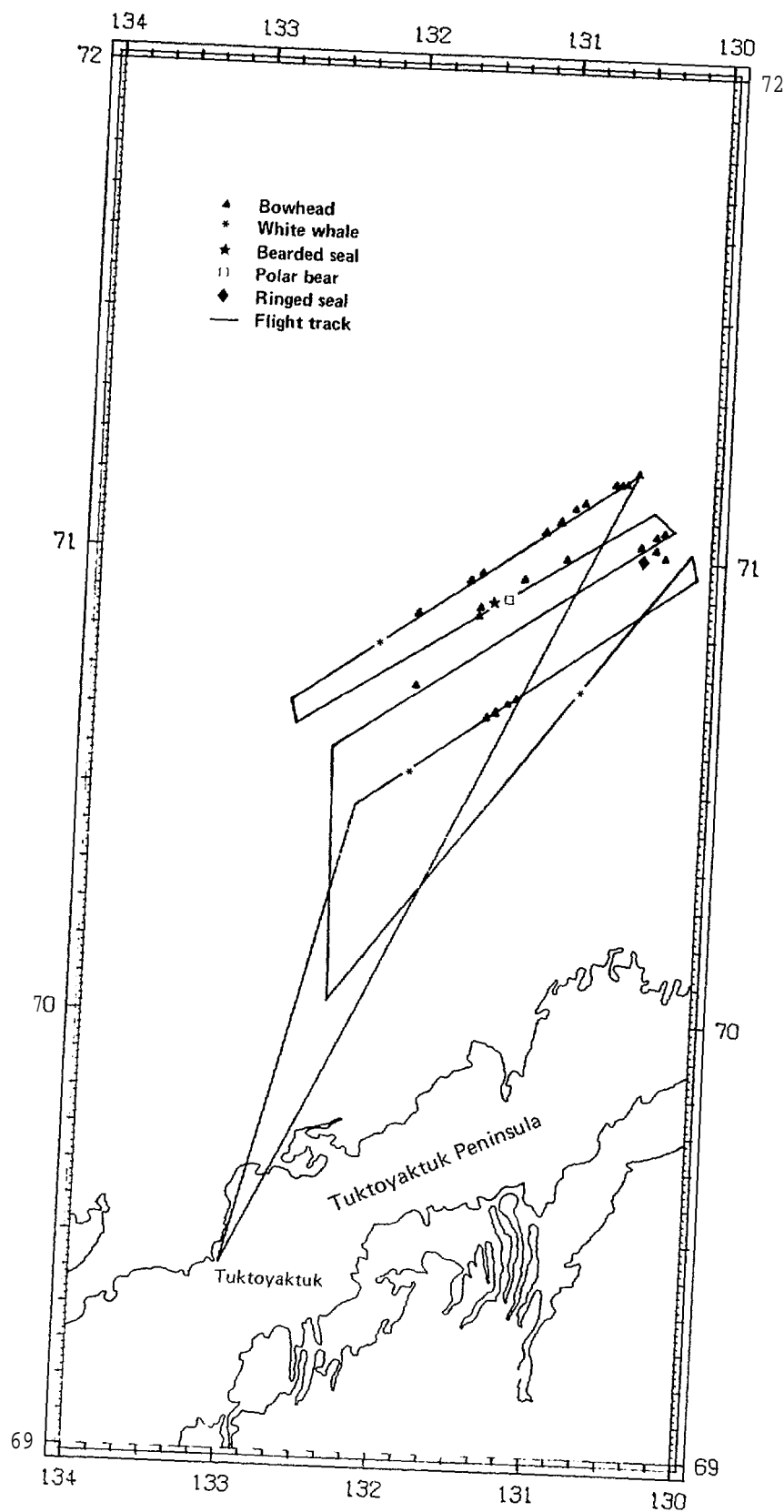


Figure 31. Aerial survey flown on 12 September to define bowhead distribution and to relocate tagged whales. There were 25 sightings of 37 bowheads, 3 sightings of 17 belugas, 2 sightings of 51 ringed seals, and one bearded seal and one polar bear sighted on this Survey.

sightings of 20 bowheads). Flights between 4 and 12 September, however, sighted large concentrations of whales 30 to 50 miles off the Tuktoyaktuk Peninsula. On 12 September, 25 sightings of 37 whales were made from an aircraft chartered to relocate tagged bowheads (Fig. 31). Despite extensive monitoring from Grumman **N780**, the LGL chartered aircraft, and a chartered **Skymaster**, no transmissions were received from tagged whales in the eastern **Beaufort** Sea after 21 August and no vessel was available for further tagging after 24 August.

The essential tagging gear was shipped west aboard Grumman N780 on 13 September when the opportunity arose to attempt tagging in the central Beaufort Sea in the **vicinity** of Beaufort Lagoon. An Alaska Department of Fish and Game team had been able to approach a few bowhead whales in a 21 ft Boston whaler there during the second week in September, but by the time the tagging effort began on 14 September, severe ice conditions had set in and only a few unsuccessful attempts to locate whales were possible. Ice conditions such as those pictured in Figure 32 made it difficult to locate and approach bowheads, even when assisted by aircraft with air-to-ground communication system. Heavy ice after 20 September ended attempts to place more radio tags on bowhead whales during the 1980 season.

From 16 September through 13 October, however, flights were made in conjunction with the **BLM** bowhead survey team to relocate the two tagged whales as they passed the **OCS** lease-sale areas during their fall migration. On one occasion during this time, a brief radio transmission was received but the presence of a tagged bowhead whale was unconfirmed by either further transmissions or visual relocation (Fig. 1).

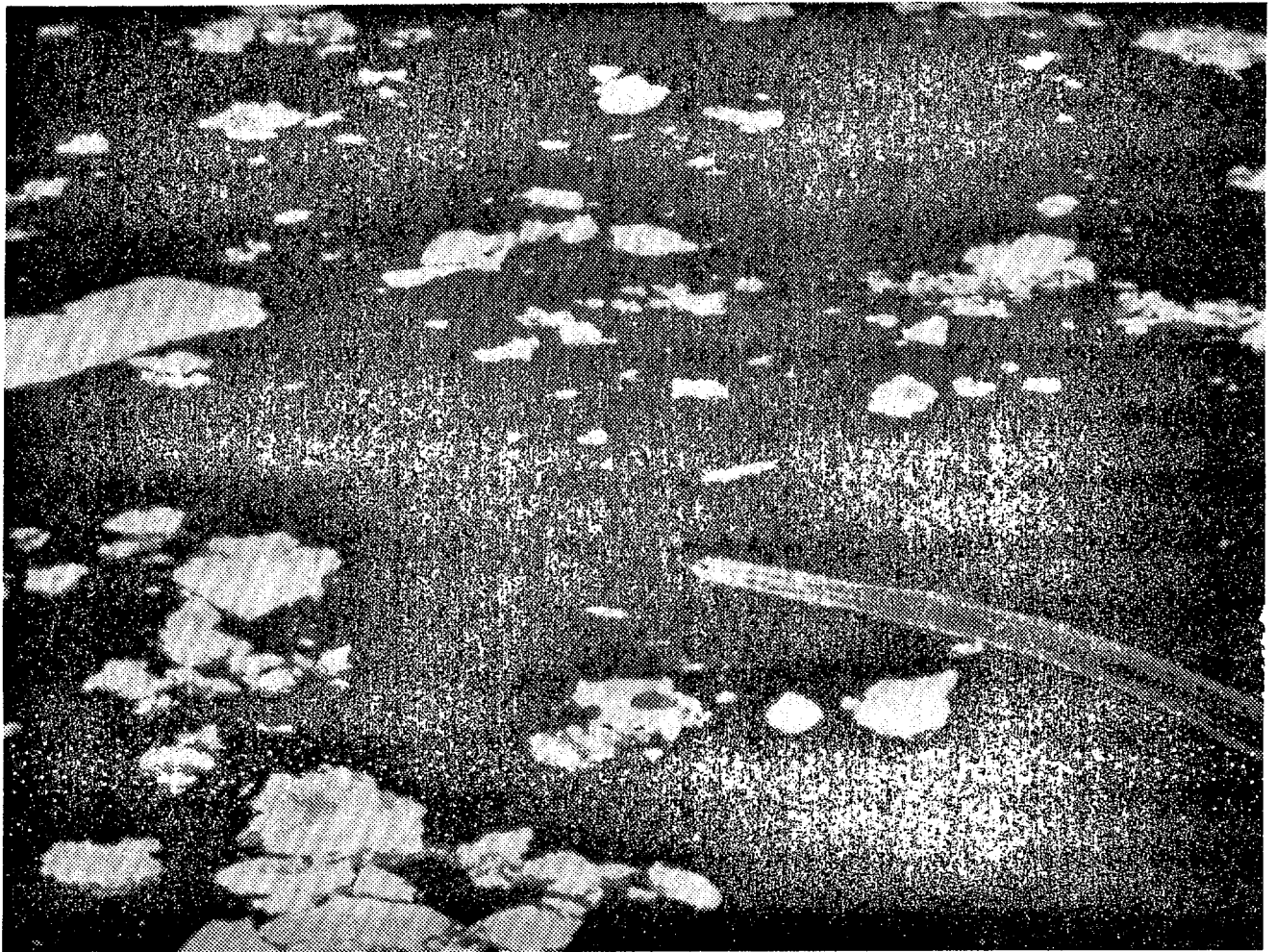


Figure 32

In September tagging efforts continued near Beaufort Lagoon, Alaska. Ice conditions shown here were unfavorable for locating and tagging whales in a small boat.

Discussion

As in any **first** year research in a remote area, logistical problems required an inordinate amount of time and effort and in some cases made it impossible to realize research goals. For example it was not possible to test the umbrella stake attachment or to photo- and videodocument the tagging effort because the scientific party aboard Ungaluk, with two distinct and immiscible research methods, was too small to accomplish these tasks. The lack of a **truly** reliable and seaworthy vessel capable of reaching whale concentrations quickly and staying at sea for an extended time was, and remains, the predominant problem in **working** on bowhead whales in the Beaufort Sea. The ideal vessel should be large enough to:

- 1) weather the most severe storms encountered during the summer and fall;
- 2) carry a crew capable of safe vessel operation around the clock for at least 2 weeks; and 3) accommodate a scientific party of sufficient size to carry out **all-facets** of the research without undue stress (24 hour **watches**, tagging, photodocumentation, oversight). Because vessels are extremely expensive in the Arctic (\$3,000/day minimum), a smaller, high speed vessel which could house a ship's crew of at least three and a scientific party of at least four might serve as an alternative. Such a vessel could reach whale concentrations quickly during **breaks** in the weather and run from foul weather as it approached.

The results of this study and some previous studies (for example, Norris et al. 1976) suggested that aircraft may be ineffective for relocating radio tagged cetaceans except in very special circumstances such as populations with highly defined migratory pathways or confined home range. The problem arises from the interpretation of negative data (i.e., does "no signal" mean the animal was not in the area covered by

the aircraft, the transmitter had fallen off, the animal did not surface while the aircraft was within **range**, or the antenna angle precluded **signal** reception?) and the low probability of encountering a given cetacean in the relatively small area possible to search by an aircraft. The latter problem is compounded when the relocation effort is combined with aerial surveys since transmission reception is cut by $2/3$ to $3/4$ at the lower altitudes necessary for visual sightings. Distance trials using a test transmitter showed that the survey aircraft flying at 1,000 ft. over about a 40 mile swath (20 miles on each side) and received signals over about a 140 mile swath flying at 8,000 ft. Thus, a signal **could** be detected from a given point on transect (**e.g.**, a surfacing whale) for 1 hour and 10 minutes at 120 knots from 8,000 ft, while at 1,000 ft the aircraft would pass out of contact with that point in 20 minutes. Although far larger than surface vessel coverage capability, the relocation area covered by aircraft **at** reasonable cost, even at high altitudes, is quite small compared to the area of habitat available to highly mobile or **noncoastal** migrating cetaceans.

Some of the problems of aircraft location are solved if remote stations can be used to collect activity pattern, movement, and **migration** data from radio tagged individuals. Remote stations, however, are appropriate only for certain coastal species where a significant portion of a migratory population passes within range of the **receiving** antenna or where tagged individuals remain within range of the receiver for a prolonged period. Since this research sought to gather data on the coastal movements of bowhead whales, a contract was awarded for a prototype self-contained, portable, automated data collection unit

which could scan a selected number of frequencies at variable scan rate and reliably record time, frequency, and pulse interval for any received pulses over a two-week period. Also, since the amount of data collected during a shipboard or aircraft radio tracking study can be prodigious, the automated data collection unit, which will code and store information on **computercompatible** magnetic tape as well as hard copy (ticker tape), should greatly facilitate data reduction. Unfortunately, due to a supplier delivery failure, the prototype unit was not available for testing during the 1980 field season.

The greatest difficulty in tracking whales using **VHF** radio tracking systems has been the lack of an ADF capable of giving an instantaneous directional readout of short pulse VHF signals without tremendous gain loss and thus greatly diminished tracking distance. Before truly successful operational shipboard and aircraft VHF radio tracking can proceed, a **VHF-ADF** must be available which is comparable to that developed by Martin et al.(1971) for lower frequencies (**HF**).

As Mate (1980) pointed out, identifying individual transmitters with unique frequencies adds to the problem of aerial reacquisition since an animal on the surface might be missed during a receiver frequency scan even while within reception range. In order to alleviate this problem in this study, 15 transmitters were placed on the same frequency and individually identified by a unique interpulse interval as measured by a pulse analyzer (**Telonics, Inc.**). This system ensured no loss of reception due to a frequency scanning but had three major drawbacks: 1) three clear, strong pulses must be received to determine identity, and these pulses may not be received due to poor antenna orientation or

short surface time; 2) the interpulse interval may vary over time in the field, although laboratory tests demonstrated stability to within 10 milliseconds; and 3) confusion can easily develop while tracking a tagged whale if another tagged whale is nearby or a transmitter is accidentally actuated as was the case on 21 August, 1980. If frequency scanning is to be used in the future, a locking scanner would clearly facilitate tracking. The modified scanner would hold onto an incoming signal so that the tracker knows which frequency to monitor on the following whale surfacing.

One of the goals of this research was to determine the response of bowhead whales to tagging. From previous experience with spaghetti tagging whales and capturing and handling a variety of large and small cetaceans, no adverse reaction to tagging was anticipated. Additionally, Mate (1979, 1980) observed very little reaction to the placement of umbrella stakes or barnacle tags on gray whales and even noted continued "friendly" or curious behavior after tagging. In reviewing thirteen tagging attempts with the WHOI/OAR whale tag on three species of whale, Watkins (1981) describes short term whale reaction to vessel maneuvering but almost no reaction to tagging per se. Others who have used the WHOI/OAR tag had reported some short-term behavioral disturbance and suggest that tagged animals are perhaps "more wary" than usual of approaching boats"

(Marine Mammal Division 1977; J.H. Johnson, National Marine Mammal Laboratory, NMFS Northwest and Alaska Fisheries Center, Seattle, WA 98115, pers. commun.). The reactions observed in the bowhead tagging study did not differ from those previous observations. When approached by motorized vessel, bowheads generally showed some sign of avoidance.

However, when approached quietly, by sail or by oar, only the slightest reaction to tagging was noted.

The reasons for loss of signals from the two tagged whales remain largely unknown. Certainly the antenna cable connector shorts were partially responsible for the signal loss aboard Ungaluk. However, it is useful to speculate on two other possibilities: 1) the signal may have been lost due to low level inversions over the cold water (Watkins discontinued using VHF frequencies for radio tracking for this reason), and 2) **although** it seems very unlikely because of complete deployment, the transmitters may have been dislodged immediately by the whales. Further tests involving simultaneous tagging with HF and VHF frequency transmitters should determine the relative effectiveness and efficiency of each frequency as well as test for effectiveness of attachment and the effect of possible inversions upon signal reception.

In conclusion, the bowhead whale tagging program experienced mixed success. One of the major goals of the research, the determination of the feasibility of open ocean tagging of bowhead whales without harm to whales or taggers was completely realized and successfully accomplished and the logistical fabric for future work in the **Beaufort** Sea was established. In addition, this research suggests that 1) the use of aircraft for primary relocation of wide ranging, tagged whales is generally inappropriate, 2) a VHF-ADF for shipboard and aircraft tracking must be developed, and 3) further bowhead tracking requires a suitable vessel with crew and scientific party of sufficient size and dedication to insure success. Both barnacle and umbrella stake tags deployed and held well in laboratory tests on bowhead blubber, and barnacle tags deployed perfectly in the field trials. Therefore, if a suitable vessel could be

acquired, there is **great** likelihood that a very successful **tagging** and tracking **program** could be achieved with bowhead whales.

SATELLITE-LINKED TRANSMITTER DEVELOPMENT

Because of the high cost and often overwhelming logistical considerations involved in radio tracking 'cetaceans by ship and aircraft in the open ocean, responsible agencies and scientists have shown great interest during the past decade in the development of satellite-linked tracking and data collection. In order to attach satellite transmitters to whales utilizing existent techniques (i.e., **WHOI/OAR** tag, barnacle tag, umbrella stake **tag**), currently available transmitters need an exponential reduction in power requirements because batteries comprise the major portion of their mass. A contract was awarded for the development of a processor-controller which would maintain constant frequency stability, format and sequence message outputs, and process incoming environmental and physiological parameters at very low **energy** cost. However, the CMOS chip which was being commercially developed and therefore available at low cost for use in the processor-controller failed to meet production specifications and the transmitter development program was discontinued.

One of the most important considerations prior to undertaking a satellite tracking **program** was to calculate the probability of locating a whale **given** the orbiting characteristics of the satellite, the data necessary to solve the location algorithms, and the **surfacing** characteristics of the whale species being studied. While data is readily available concerning the satellite and problem solutions,

dive-surface profiles are available for only a few species, and even these profiles do not cover the wide **range** of activity patterns exhibited during the life cycle of the species. In actuality, a large enough sample size to ensure accurate profiles can only be obtained by radio tracking experiments.

There are two approaches that can be used to determine the probability of locating a whale by satellite. First, if information is available on the time interval between successive surfacings and if this variable can be fit to some known distribution (for example, the normal distribution), it is possible to simulate a dive pattern by selecting numbers at random from the appropriate distribution. The series of times between successive surfacings can then be summed until they exceed the maximum amount of **time** the satellite **is in** view of the **transmitter**, the "window". It is assumed in this model that the duration of a dive-surface cycle is unaffected by the length of previous cycles.

Bowhead whale dive-surface data gathered by Koski and Davis (1980) and Davis and Koski (1979) from the eastern Canadian Arctic, by Wuersig et al. (1981) and ourselves from the Beaufort Sea, and by Carroll and Smithhisler (1980) from the **Chukchi** Sea indicated that these whales exhibit a wide variety of activity patterns. Mean dive times range from 3.2 min to 9.6 min with large variance, and mean surface times **range** from 1.09 min to 1.69 min again with a large variance.

Wuersig's dive profile indicated that there were two distinct dive patterns: a short cycle which lasted an **average** of 105 sec (**s.d.** 39 sec) and a long **cycle** which lasted 435 sec (**s.d.** 56 sec). It was assumed that:

1) these two patterns were equally likely and **that** dive cycles were independent **of** each other, 2) the satellite window would start in the middle of the first dive cycle, and 3) the satellite window was 780 sec (13 rein) long as *is* the case in the **Argos** system. Nine dive patterns of at least 780 sec in duration were simulated by selecting at random either the **long** or short dive pattern *and* then selecting at random from that distribution. This was repeated until the accumulated time was greater than 780 sec. Six of these nine simulations had two surfacings within the 780 sec window, one had three surfacings, and two had four surfacings. The **Argos** system requires five uplinks or "hits" and thus no location solution would **be** possible with this profile; however it has been estimated that **only** three hits would be necessary for a solution with a remote user terminal (John Bryan, Old Dominion Systems, **Gaithersburg**, Maryland 20760. November 6, 1979 pers. commune) It is clear that there are many other factors which enter into the successful location **of** whales by satellite and that a minimum of 1000 simulations should be run to **get** an accurate prediction.

A second approach is to estimate directly the probability of receiving a minimum number of hits in a specified time. Assuming that the dive times and surface times are independent and normally distributed and that the window can start when the animal is underwater **or** at the surface, the following equations apply:

If x and y are normal, where

x_i = length of time spent underwater

y_i = length of time spent on surface

given $\mu_x = \bar{x}$, $\mu_y = \bar{y}$, $\sigma_x = s_x$, $\sigma_y = s_y$;

then \Pr (animal surfaces 5 times as required for an **Argos** location fix between I and J seconds, the satellite window) =

$$\Pr(I < \sum_{i=1}^4 x_i + \sum_{i=1}^5 y_i < J) \frac{\bar{x}}{\bar{x} + \bar{y}} +$$

$$\Pr(I < \sum_{i=1}^4 x_i + 1/2 \sum_{i=1}^5 x_i + \sum_{i=1}^5 y_i < J) \frac{x}{\bar{x} + \bar{y}} "$$

Let A equal the first probability statement and B the second. Then:

$$A = \text{Standard normal probability of } \frac{J - 4\mu_x - 5\mu_y}{\sqrt{4^2\sigma_x^2 + 5^2\sigma_y^2}}$$

$$- \text{St. normal prob. of } \frac{I - 4\mu_x - 5\mu_y}{\sqrt{4^2\sigma_x^2 + 5^2\sigma_y^2}}$$

$$B = \text{St. normal } \frac{(J - 4.5\mu_x - 5\mu_y)}{\sqrt{4.5^2\sigma_x^2 + 5^2\sigma_y^2}} - \text{St. normal } \frac{(I - 4.5\mu_x - 5\mu_y)}{\sqrt{4.5^2\sigma_x^2 + 5^2\sigma_y^2}}$$

It must be remembered that the **Argos** system requires that the first and last hit be separated by at least 480 sec (7 rein) and that each transmission be separated by at least 40 sec.

Both of these approaches are really only first order approximations. Data can be more easily incorporated in the simulation procedure and it seems more flexible. The probability procedure is confounded by the fact that it is possible to get more hits than specified into the window.

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